MAPLD 2017

Mission Use of the SpaceCube Hybrid Data Processing System

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Science Data Processing Branch

NASA Goddard Space Flight Center

SpaceCube Overview

Heritage

- GOAL: close the gap with commercial processors while retaining reliability
- Started in 2006 at GSFC as R&D
- **42+ Xilinx device-years on orbit**
- 22 Xilinxs in space by 2017
- 9 systems in space by 2018
- Various R&D efforts on hardware acceleration

Hybrid Data Processing

- Parallel data processing:
  - FPGA + DSP + Processor(s)
- SpaceCube can move **3,000x** more data than a sequential processor per clock cycle

SpaceCube is a Mission-Enabling Technology

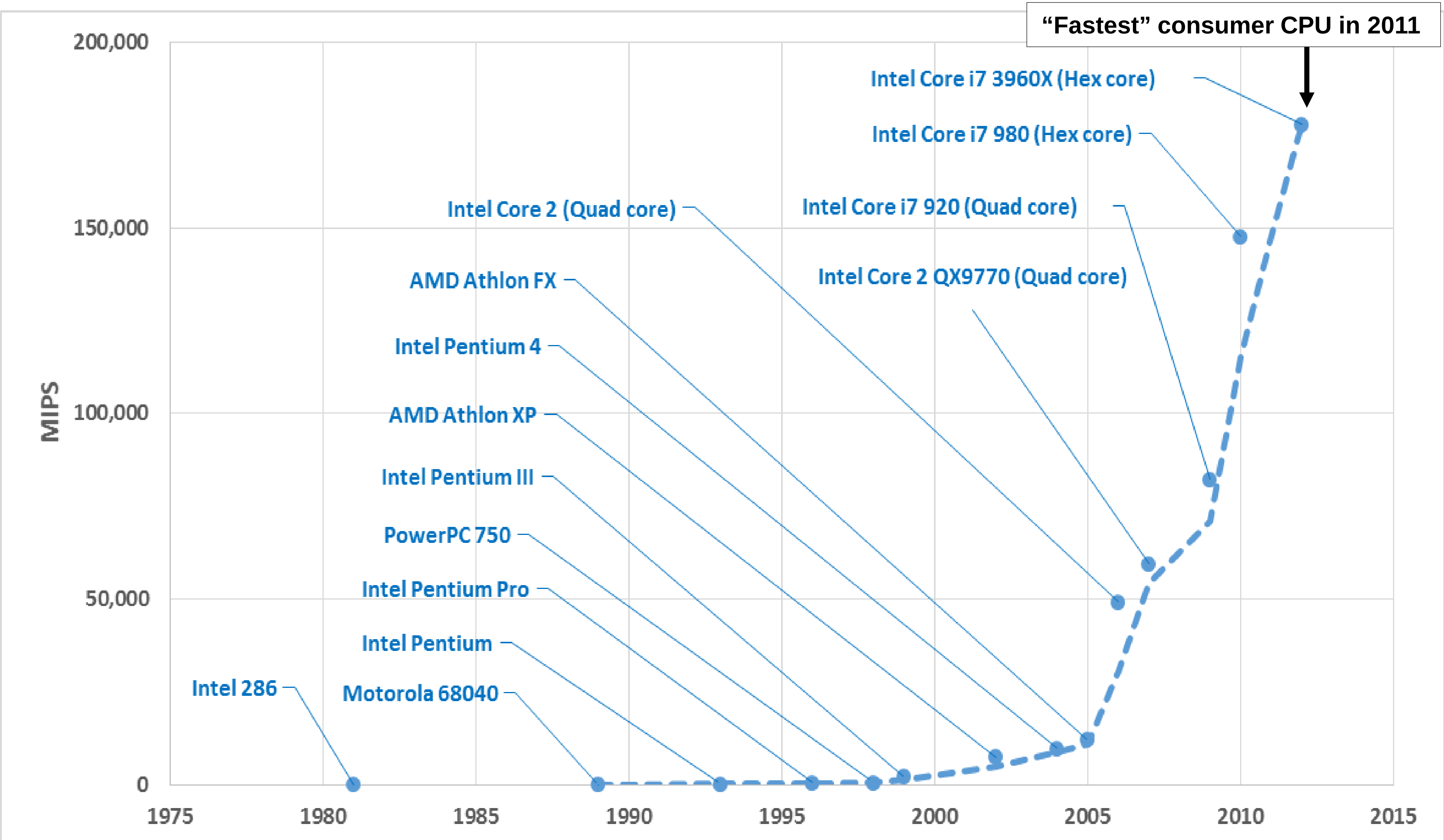
SpaceCube v2.0

- Currently TRL-7
- Leverages 10 years of design heritage and operation experience
- **$10M+ of NRE**
- Adopted by SSCO for all missions
- IPC 6012B Class 3/A PWB Reliability
- Modular: 9 Mission-Unique I/O cards
- **Run-Time Reconfigurable**

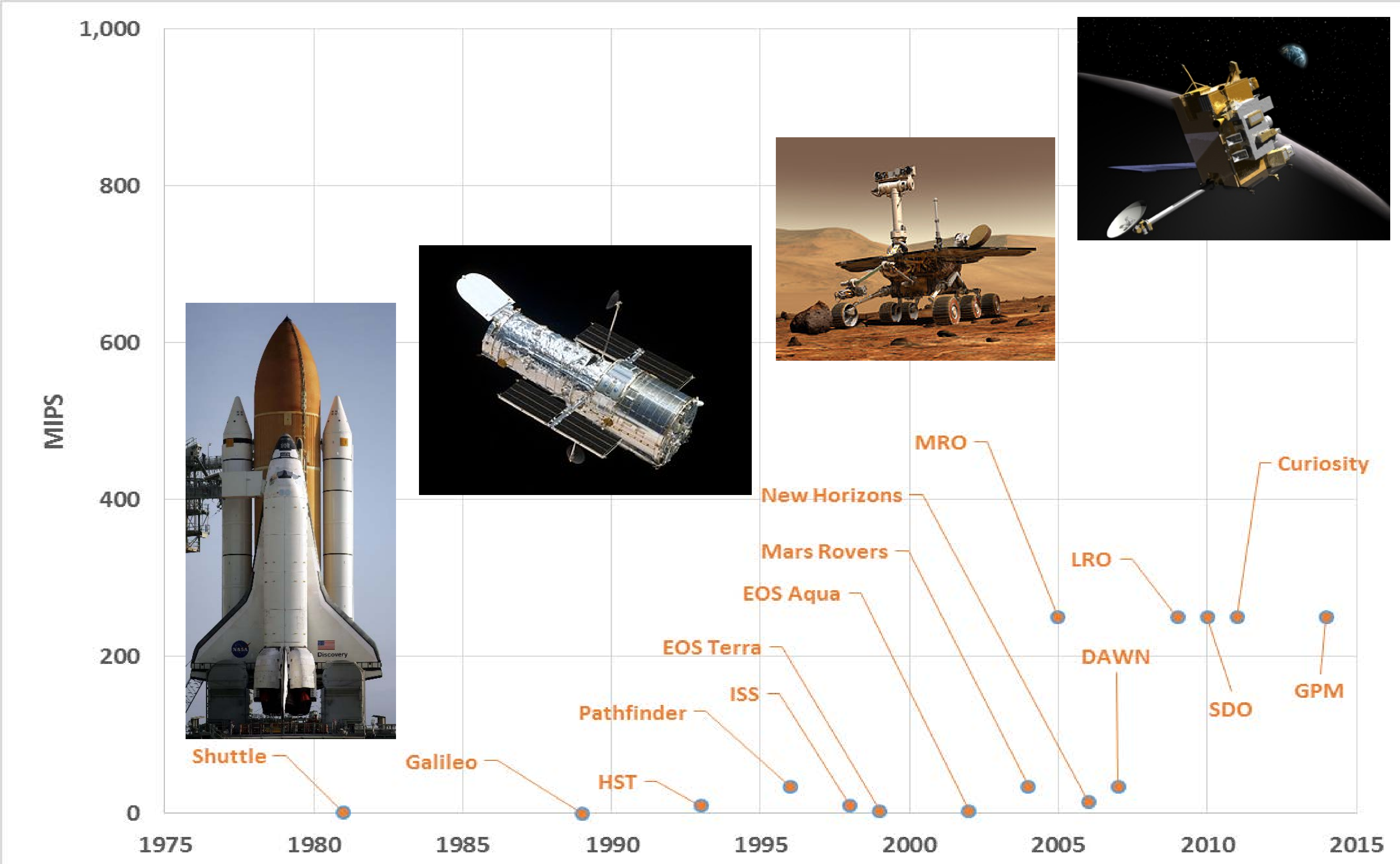
Xilinx Virtex-5 FPGA

SpaceCube v2.0

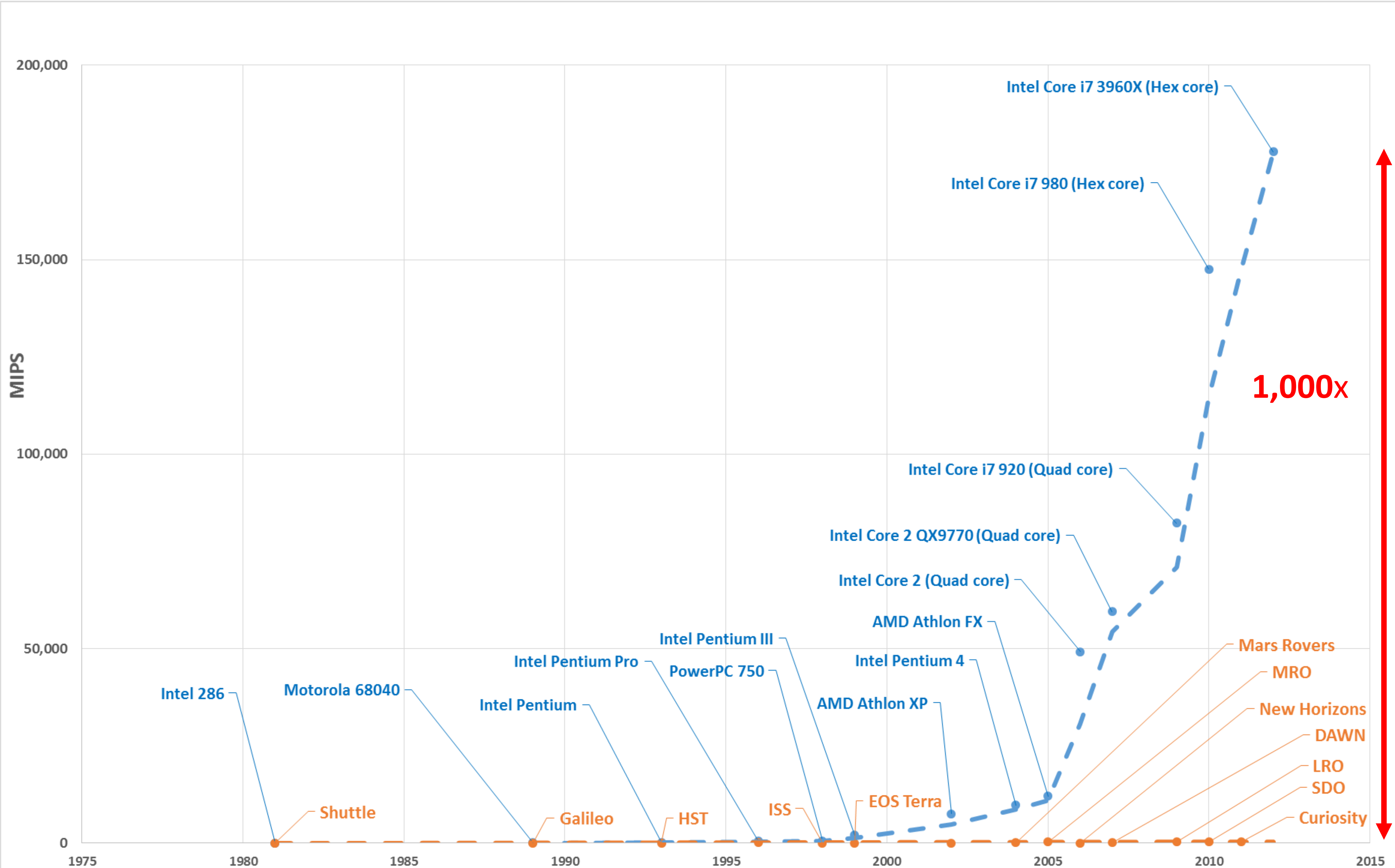
Commercial Processor Trend



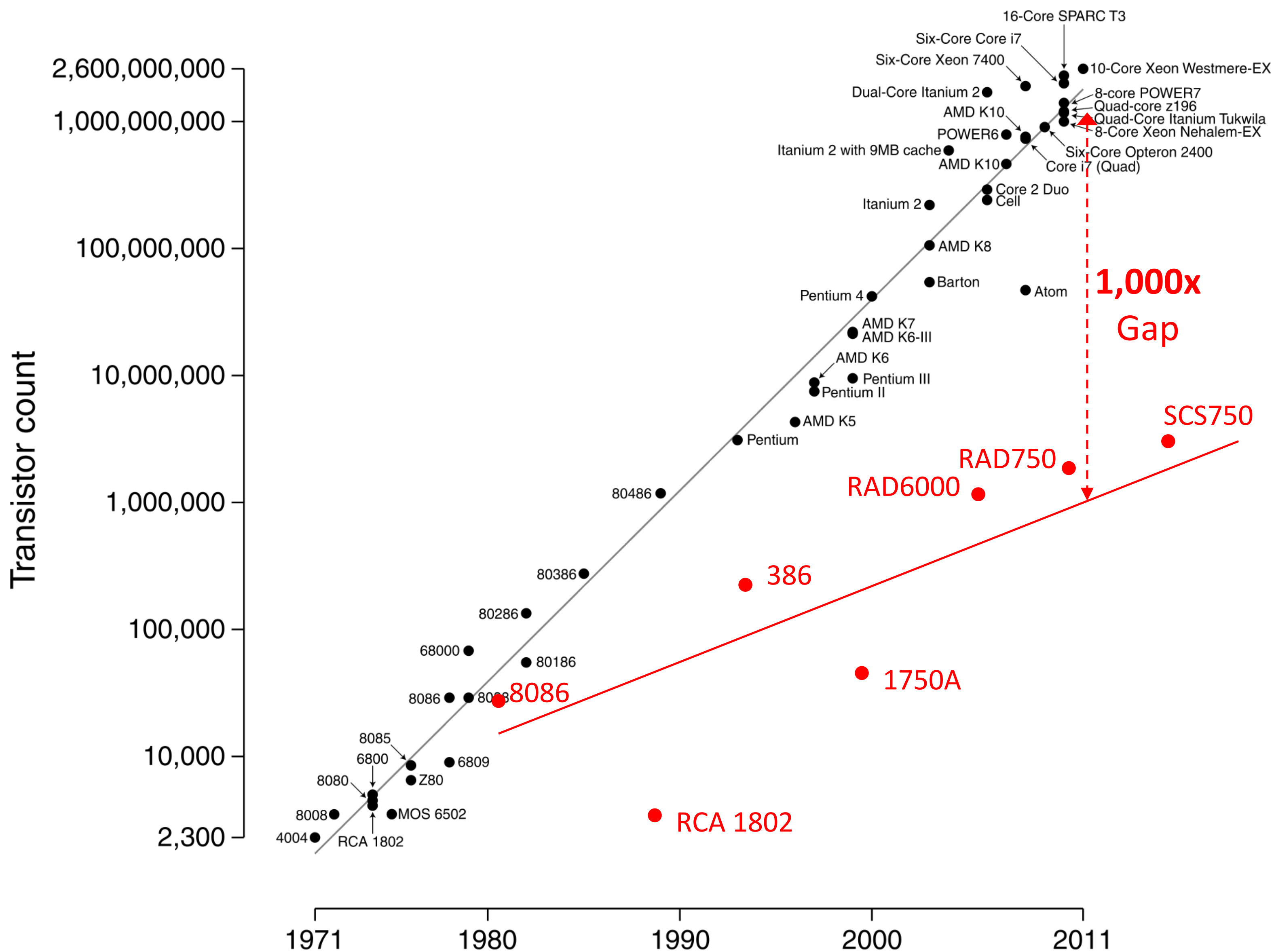
Space Processor Trend



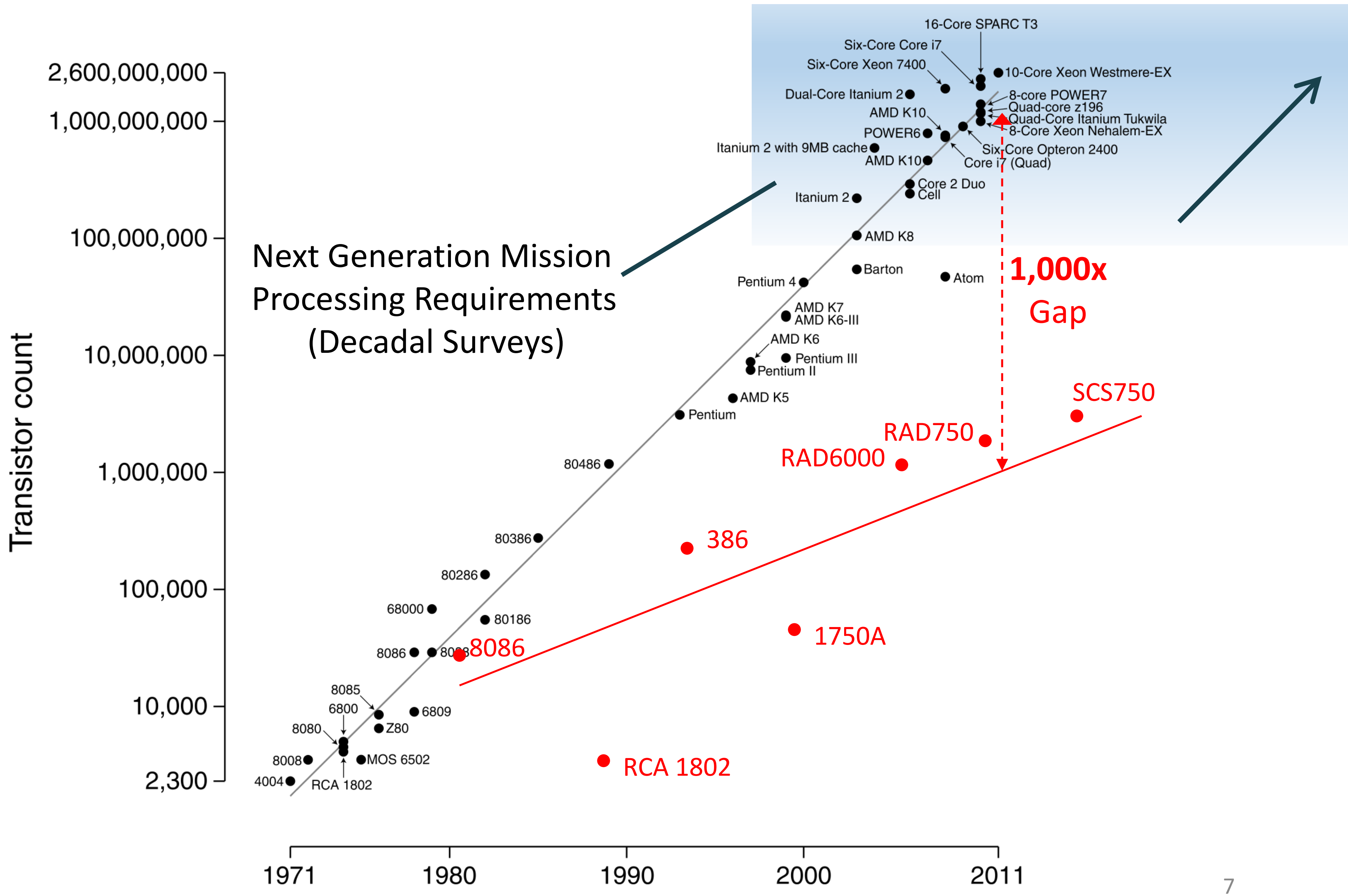
Processor Trend Comparison



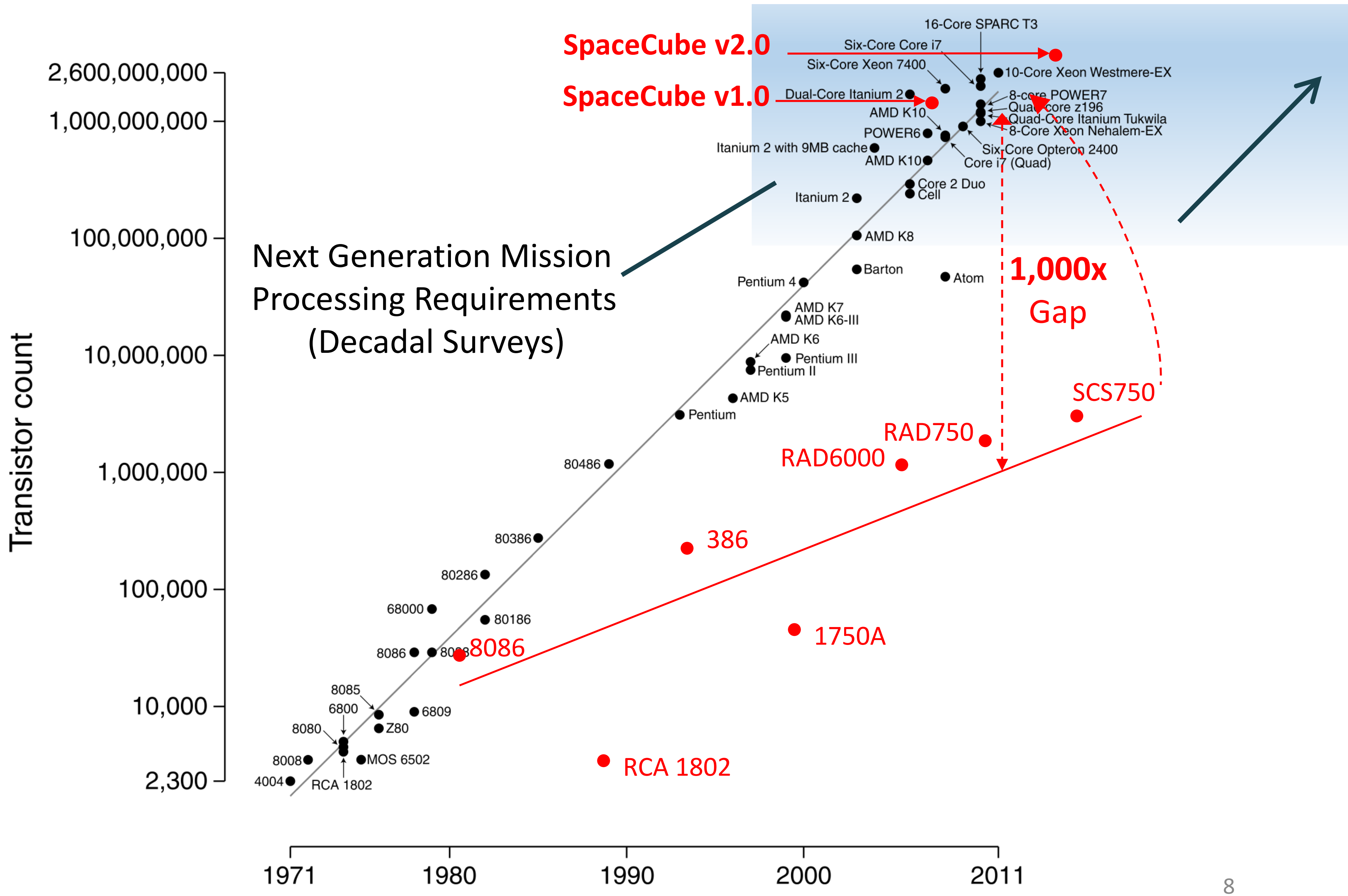
Processor Trend Comparison



Future Space Processing Requirement

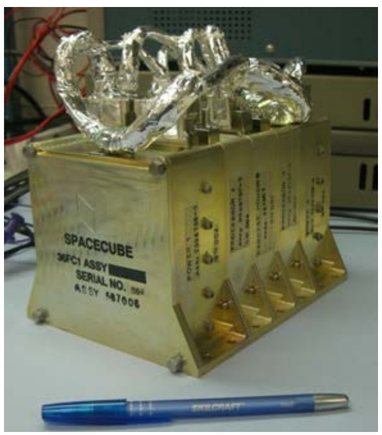


SpaceCube Closes the Gap



SpaceCube Family Overview

v1.0



2009 STS-125
2009 MISSE-7
2013 STP-H4
2017 STP-H5
2018 STP-H6

v1.5

2012 SMART (ORS)

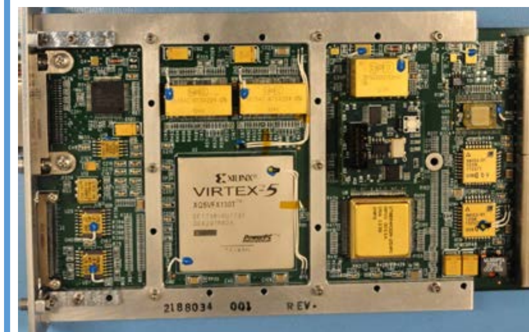
v2.0-EM

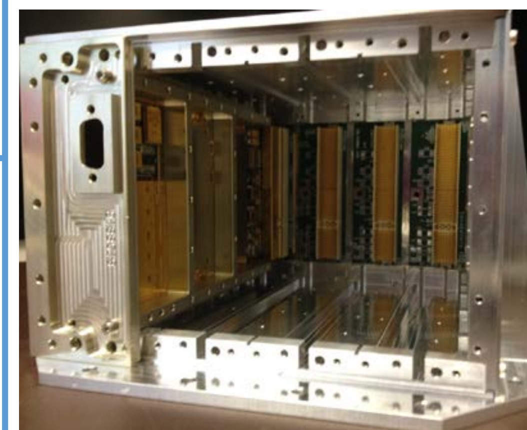
2013 STP-H4
2017 STP-H5

v2.0 Mini

2017 STP-H5
NASA proposals

v2.0-FLT





2018 RRM3
2018 STP-H6 (NavCube)
2018 NEODaC
Restore-L
Many NASA proposals

SpaceCube on the ISS

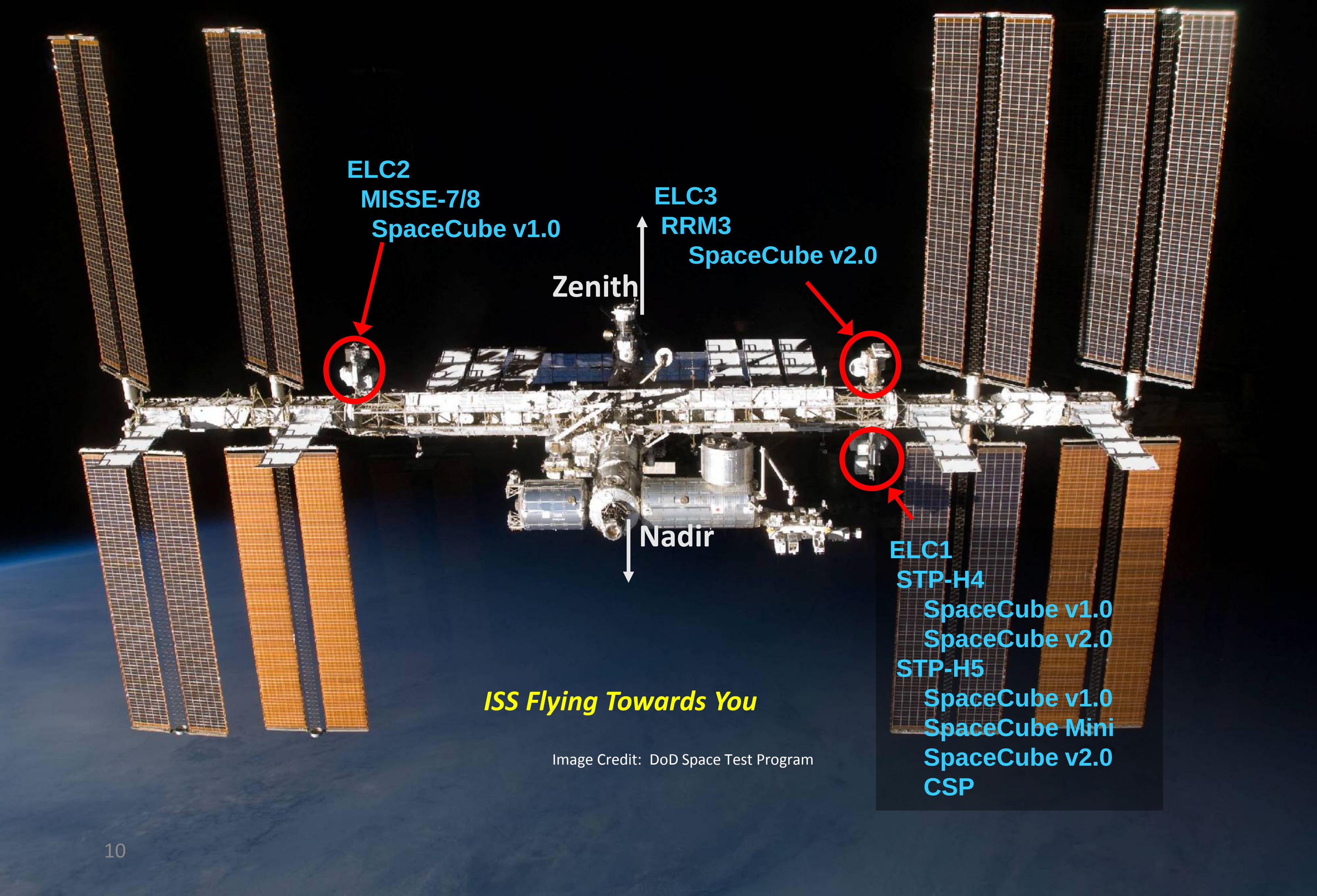
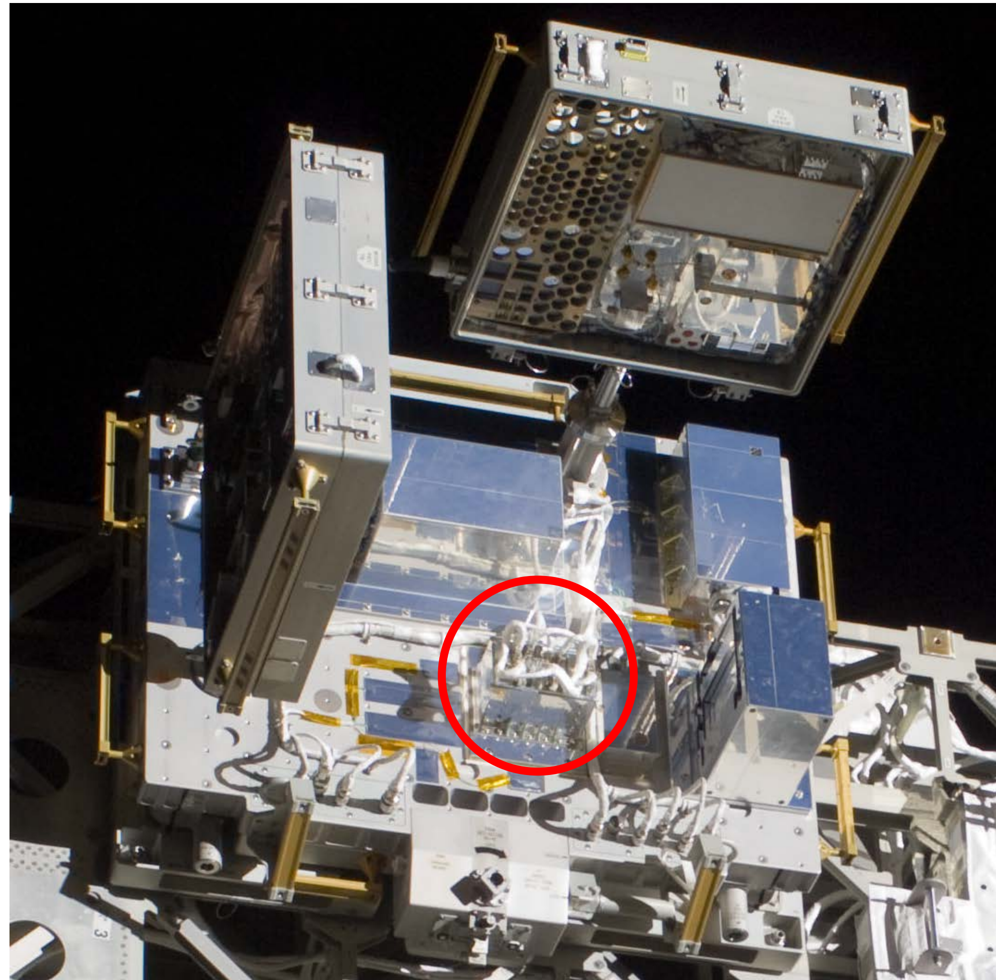


Image Credit: DoD Space Test Program

SpaceCube v1.0

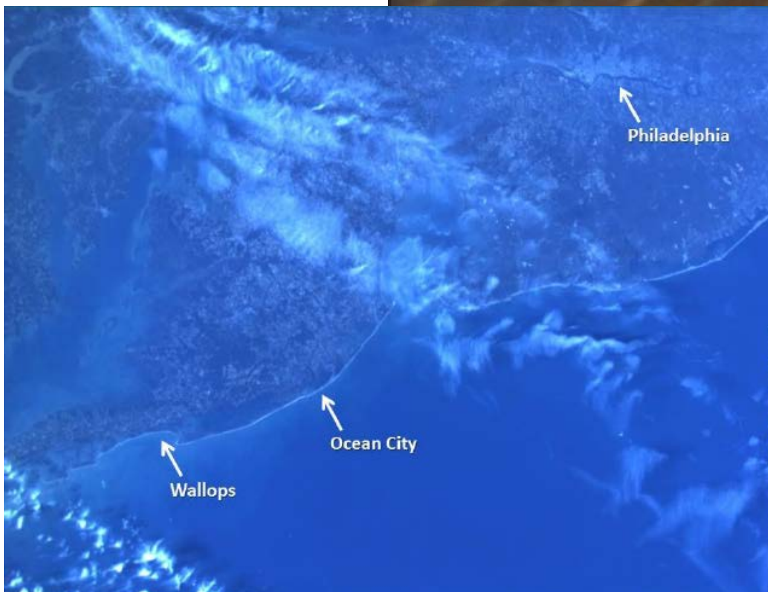
STS-125 Shuttle Payload Bay

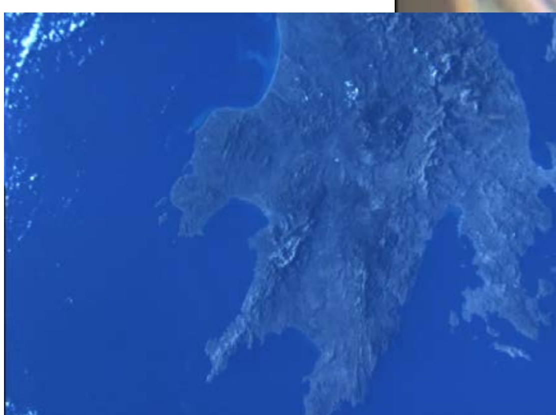
MISSE-7/8 ISS Payload

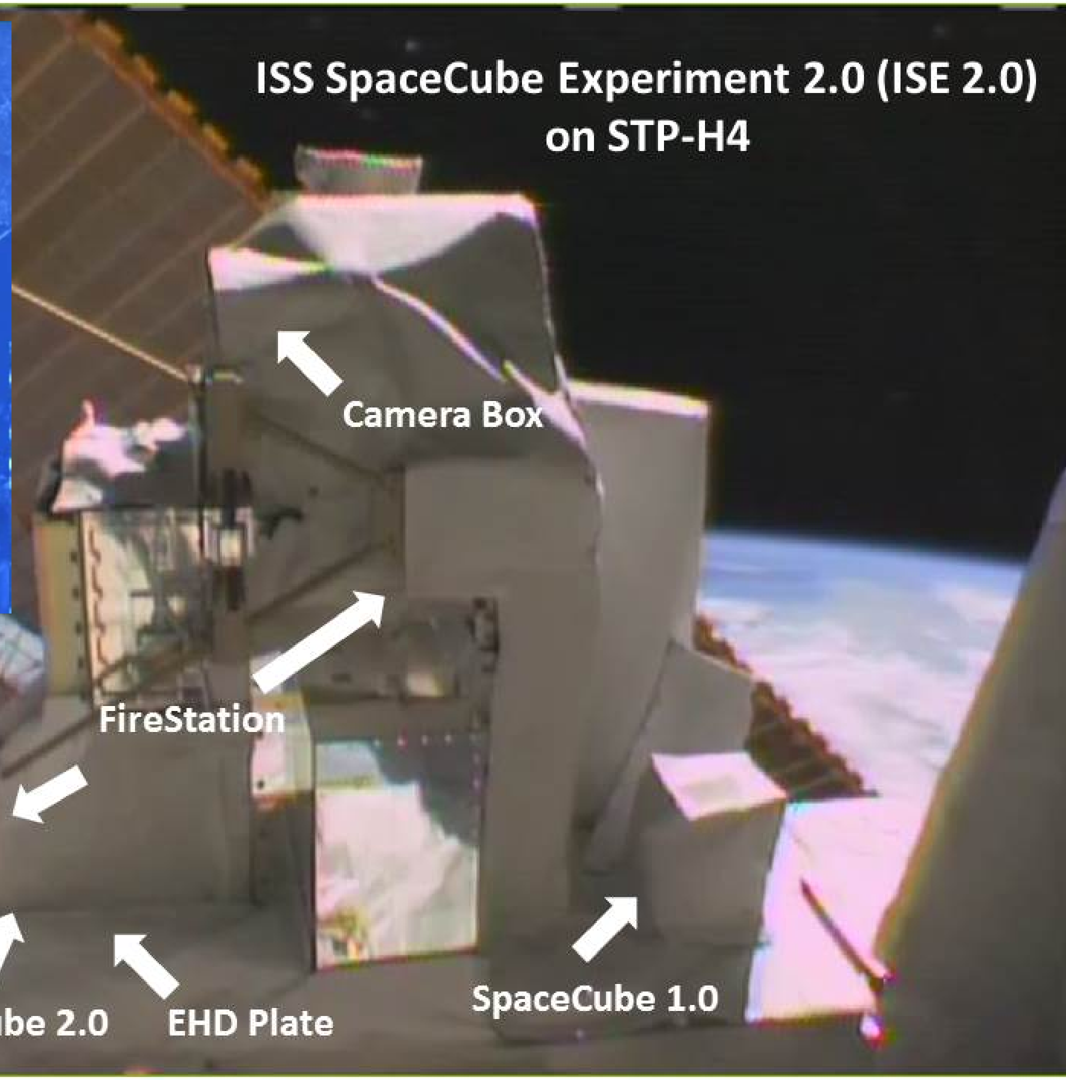


- 7.3 years of operation
- 4x Virtex-4 XC4VFX60: 0.1 SEU/FPGA/Week
- 2x on-orbit file uploads and reconfiguration

STP-H4 ISS Payload



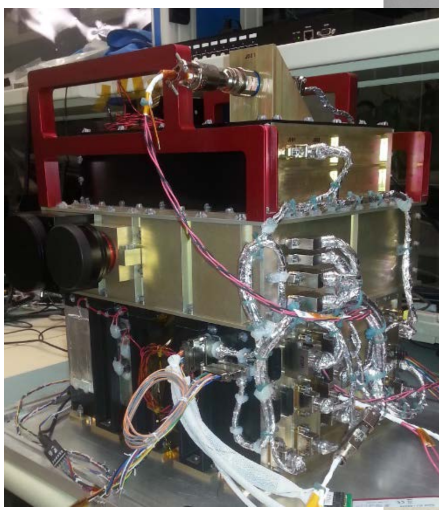


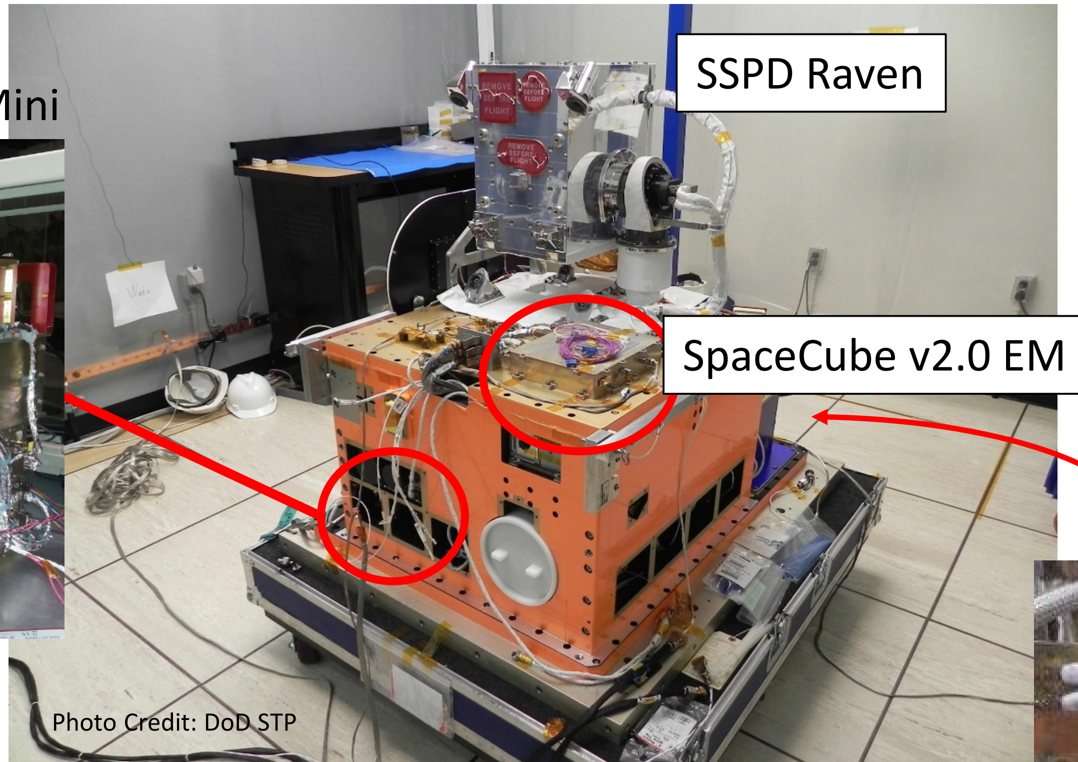


2 years of operation. 3x Virtex-5 XC5VFX130T: 1 SEU/FPGA/Week
Successful on-orbit file upload and reconfiguration

STP-H5 ISS Payload

ISEM, SpaceCube Mini





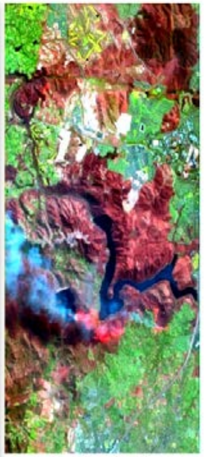
SpaceCube v1.0 CIB

The Space Test Program-H5 (STP-H5) external payload, a complement of 13 unique experiments from seven government agencies, is integrated and flown under the management and direction of the Department of Defense's Space Test Program.

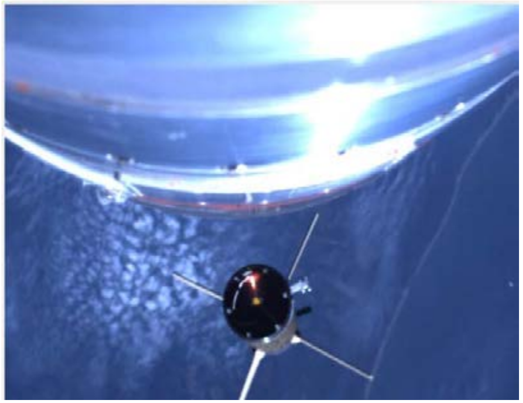
Installed on ISS February 2017

Example SpaceCube Processing

Real-Time Vehicle Tracking



Fire Classification



Gigabit Instrument Interfacing

Xilinx ISS Radiation Data

Spectrometer Data Reduction

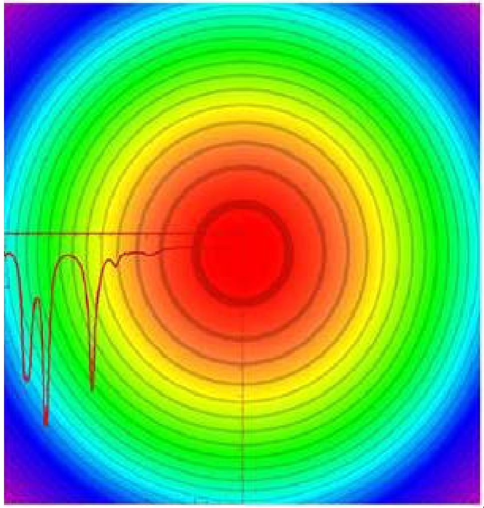
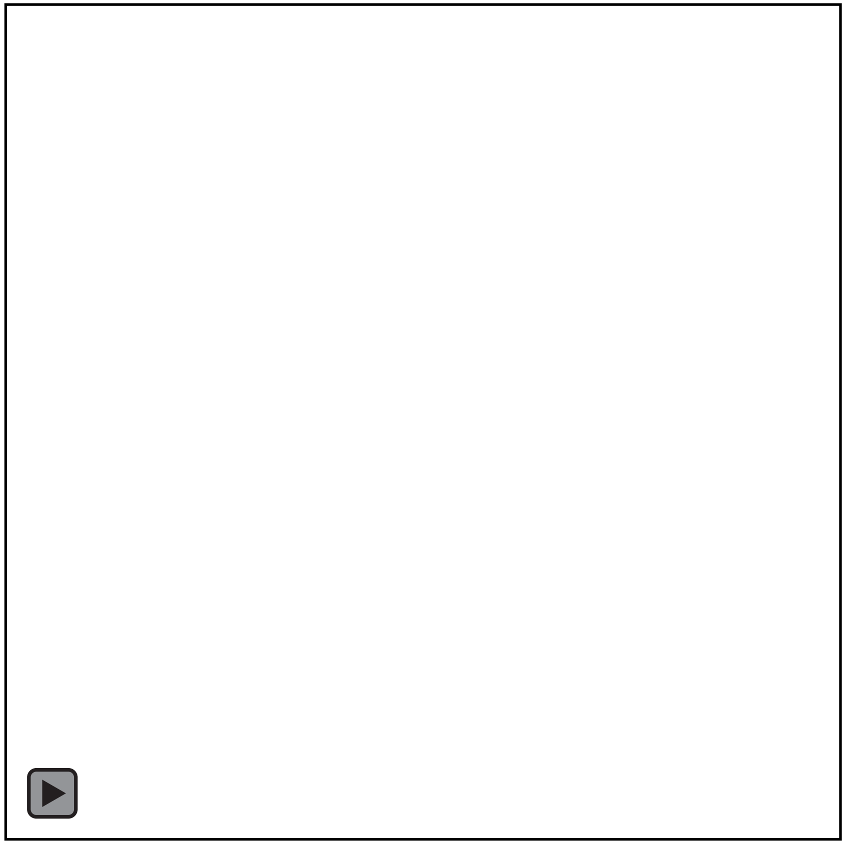


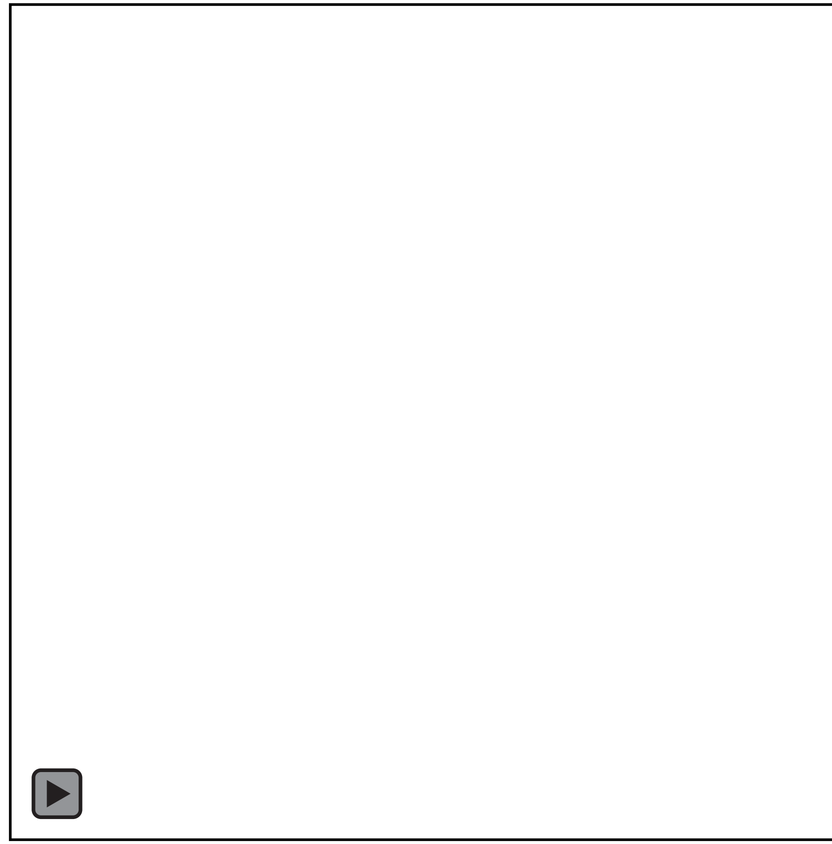
Image Compression

On-Board Image Processing Example

→ Successfully tracked Hubble position and orientation in real-time operations
→ FPGA Algorithm Acceleration was required to meet 3Hz loop requirement



Rendezvous

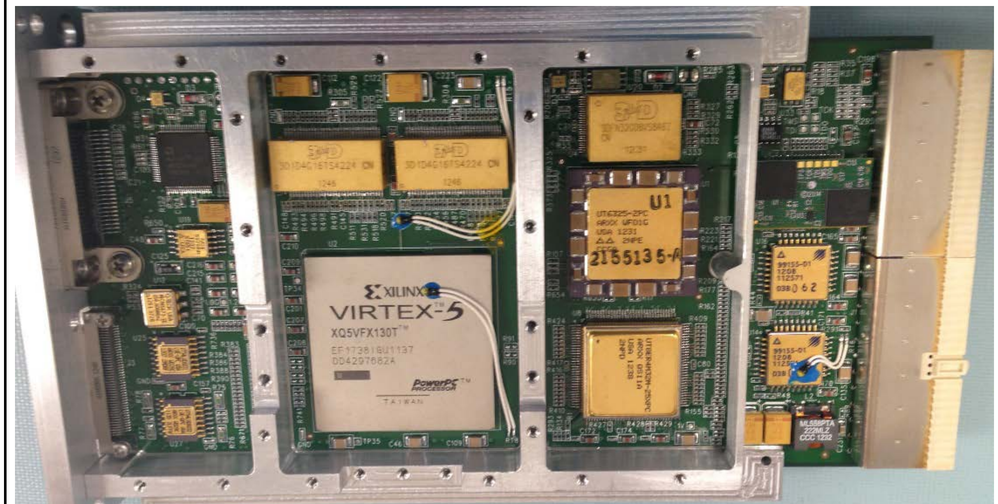


Deploy (Docking Ring)

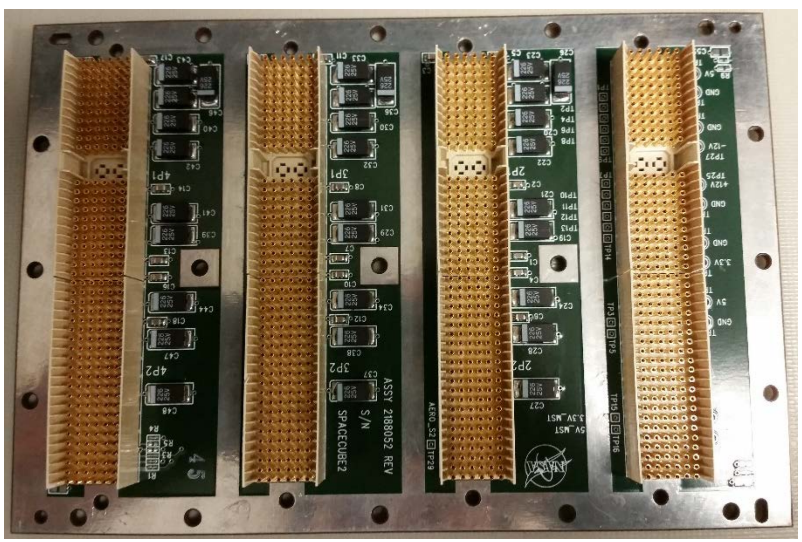
→ Typical space flight processors are 25-100x too slow for this application

SpaceCube v2.0

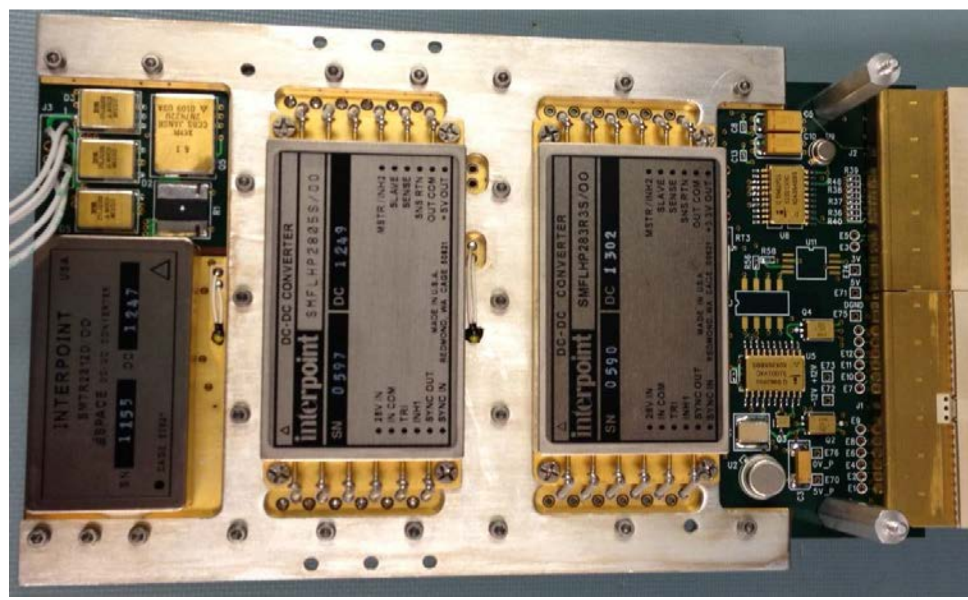
Restore-L/RRM3/NEODaC Computer



SpaceCube Processor Card

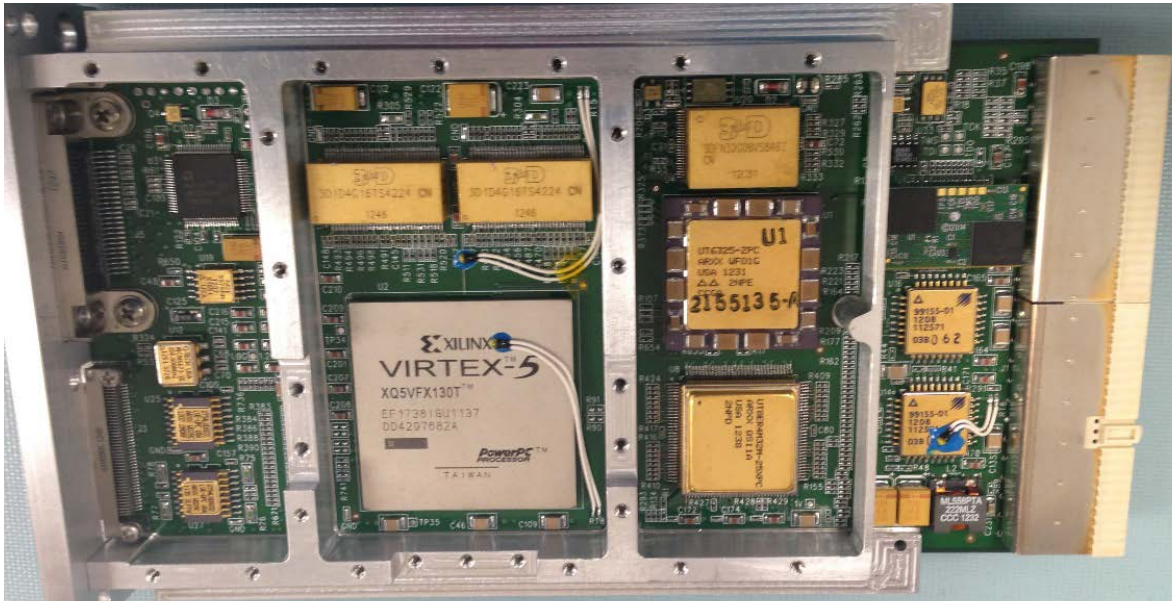


SpaceCube Backplane Card



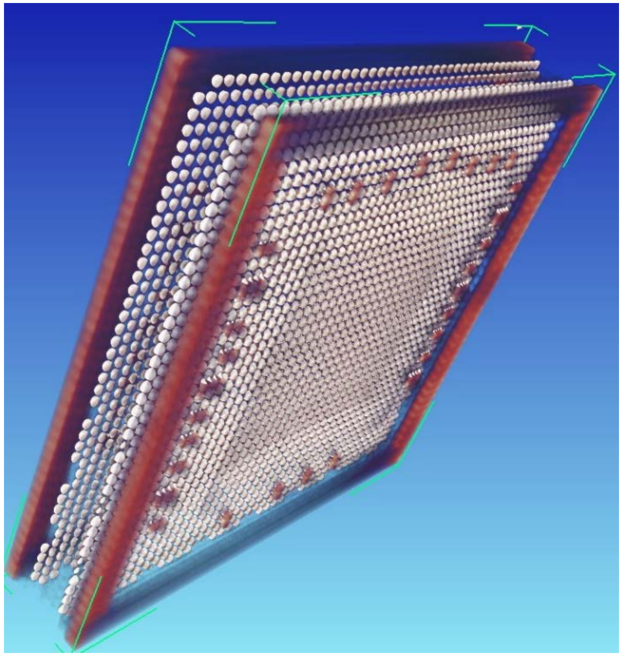
SpaceCube Power Card

Processor Card



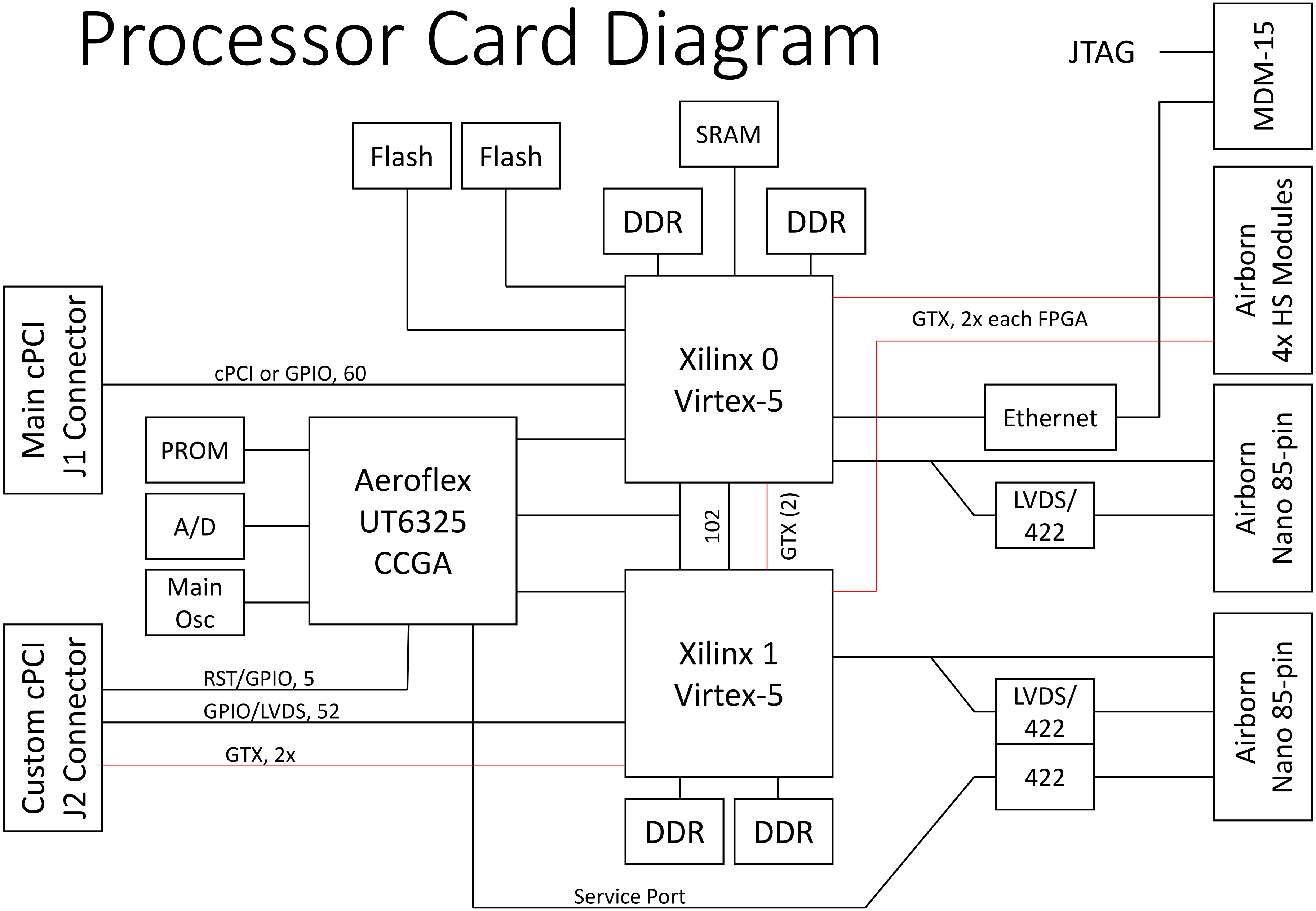
Power Draw: 6-15W
Weight: 0.98-lbs
22 Layers, Via-in-Pad
IPC 6012B Class 3/A

- 2x Xilinx Virtex-5 (QR) FX130T FPGAs
- 1x Aeroflex CCGA FPGA
  - Xilinx Configuration, Watchdog, Timers
  - Auxiliary Command/Telemetry port
- 1x 128Mb PROM, contains initial Xilinx configuration files
- 1x 16MB SRAM, rad-hard with auto EDAC/scrub feature
- 4x 512MB DDR SDRAM
- 2x 4GB NAND Flash
- 16-channel Analog/Digital circuit for system health
- Optional 10/100 Ethernet interface
- Gigabit interfaces: 4x external, 2x on backplane
- 12x Full-Duplex dedicated differential channels
- 88 GPIO/LVDS channels directly to Xilinx FPGAs
- Mechanical support for heat pipes and stiffener for Xilinx devices

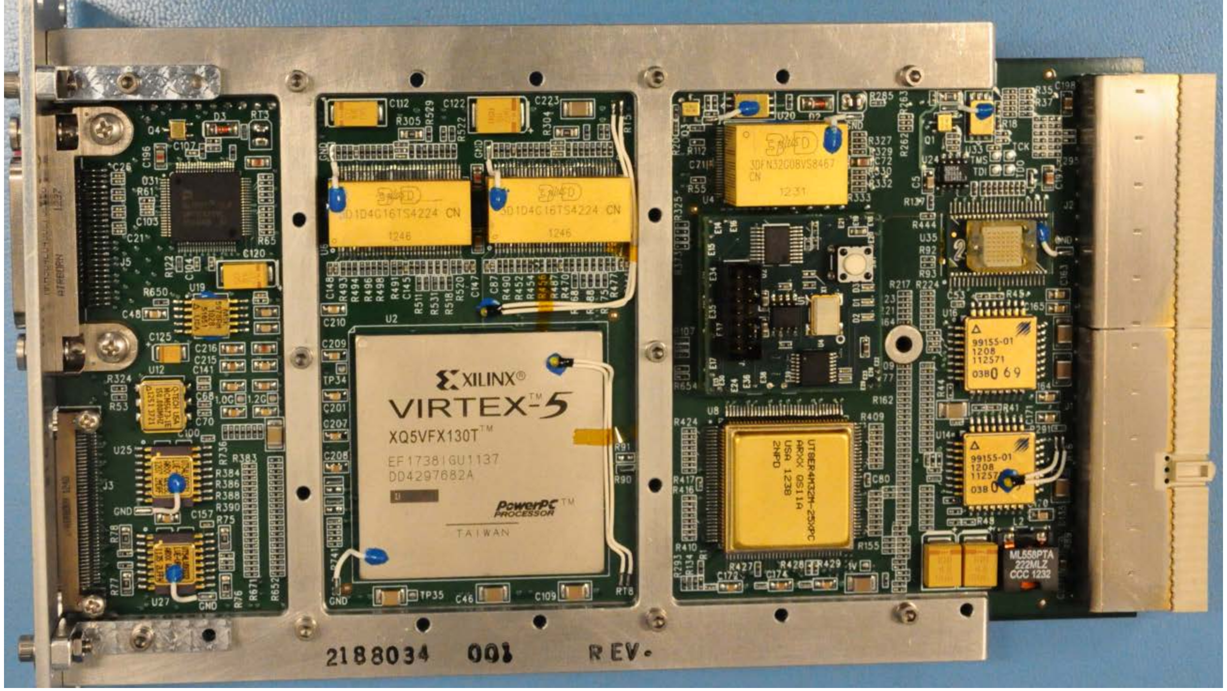


2014 Global Award: Most innovative design worldwide in the Military/Aerospace sector

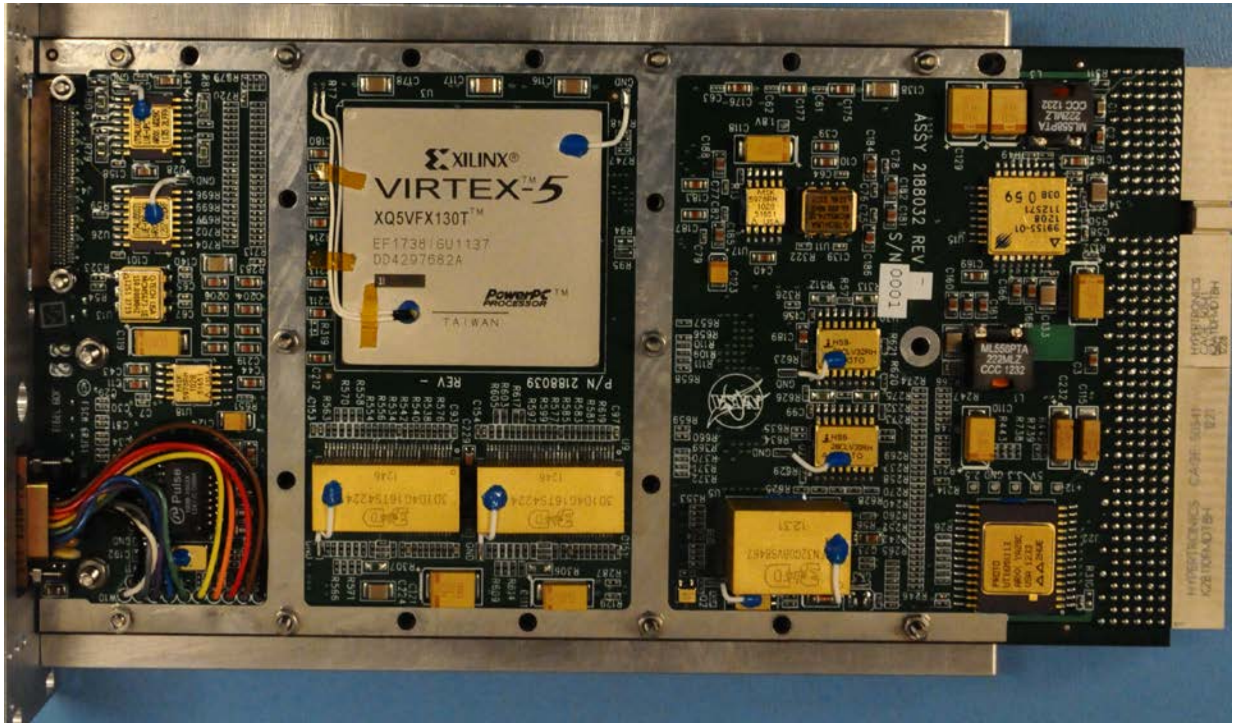
Processor Card Diagram



TOP



BOTTOM



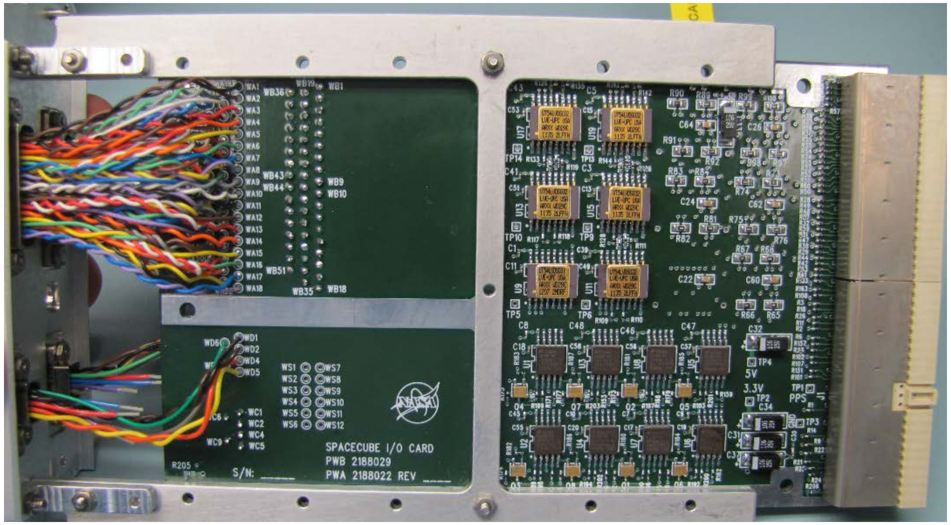
Back-to-Back Technology

US Patent: 9,549,467

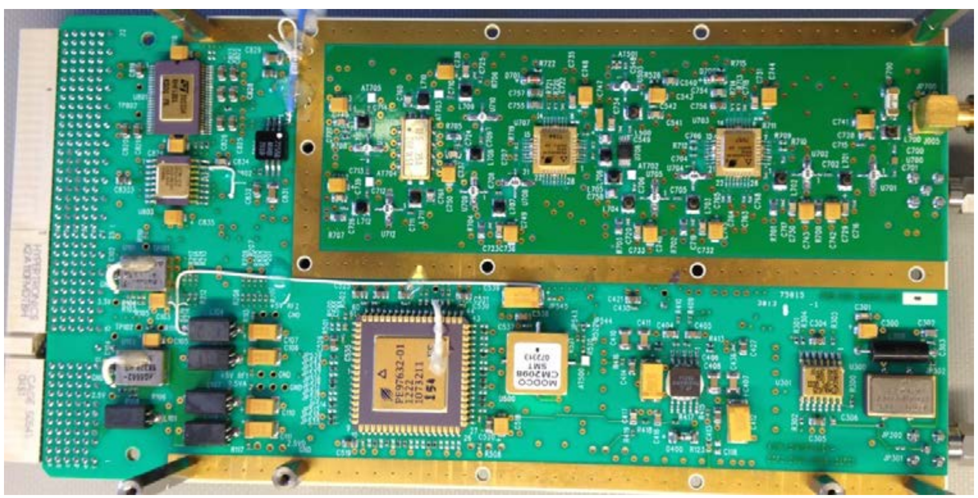
Industry license agreement in place to build SpaceCube

Example Mission-Unique I/O Cards

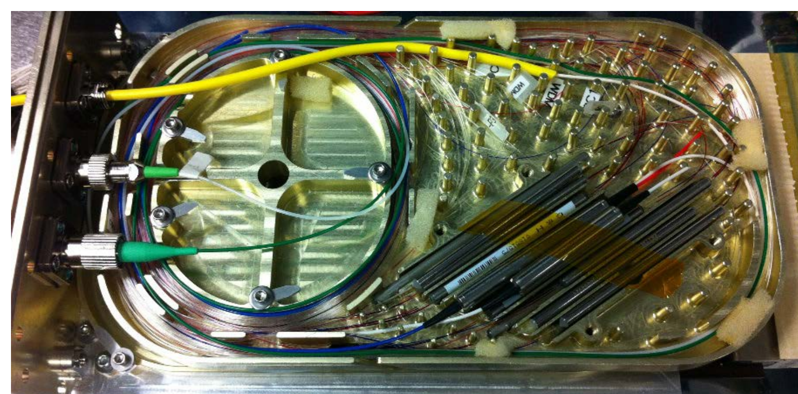
Restore-L Video/Spacecraft Interface Card



"NavCube" GPS RF Front-End Interface Card

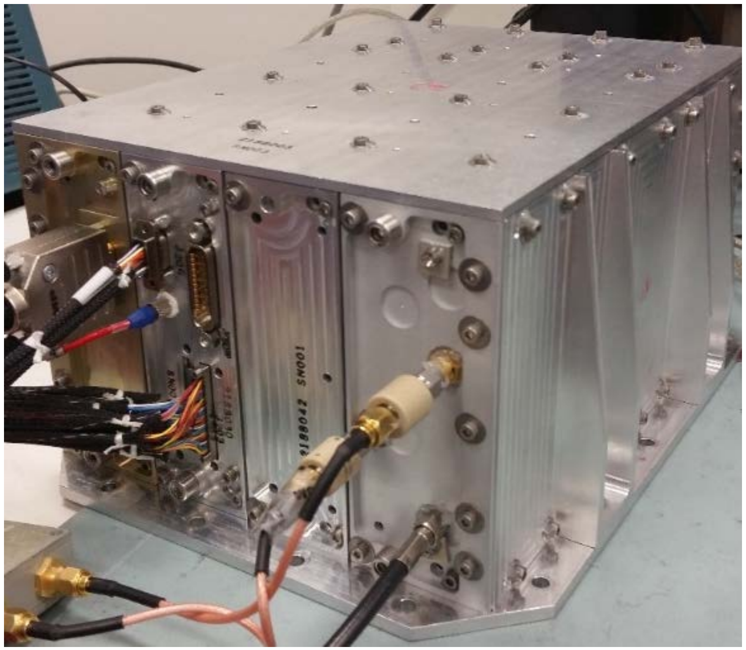


LIDAR Digitizer, Front-End, and Laser Card

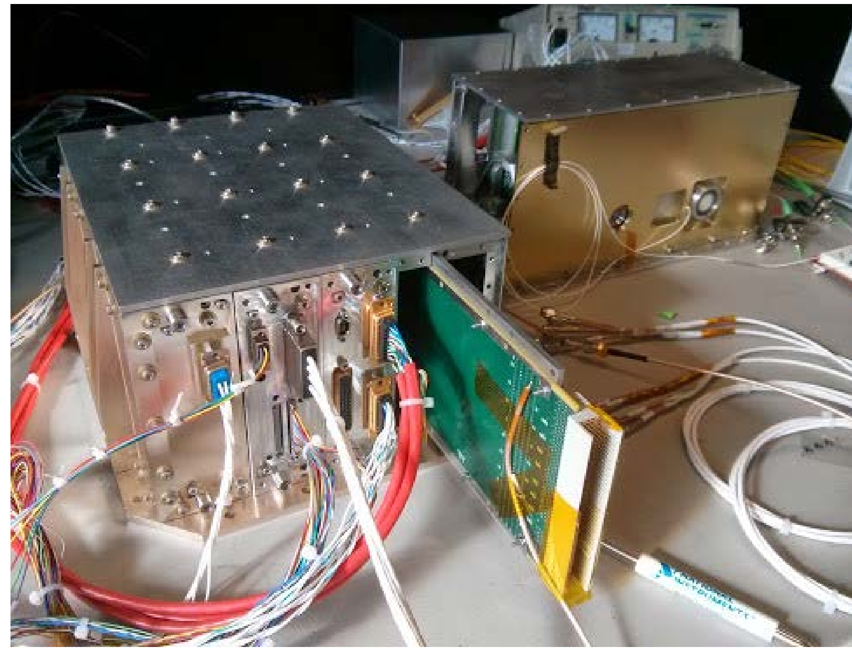


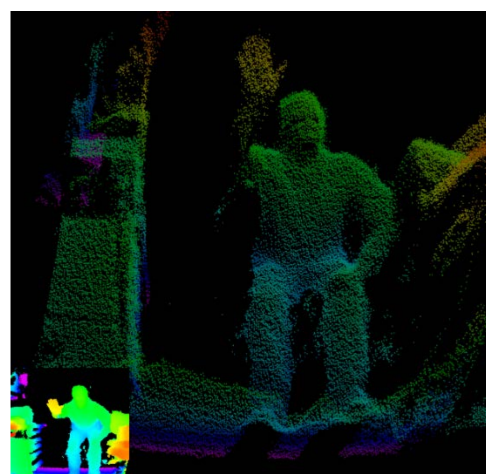
Reconfigurable + Modular = Spinoff Technologies

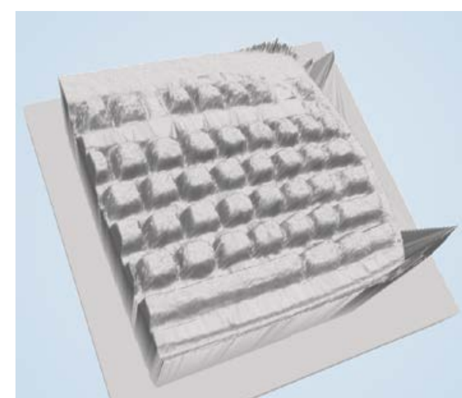
GPS Receiver – L1/L2C Tracking



LIDAR Instrument – Configurable Resolution







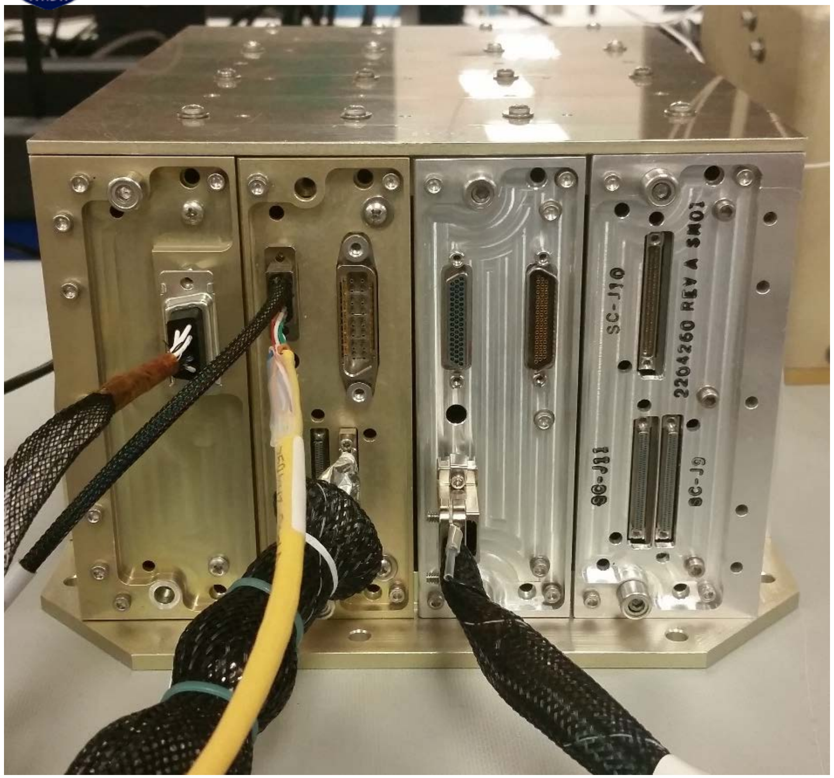
<u>“NavCube”</u>

- Port the “World Recording Breaking” Navigator technology to SpaceCube
- Full qualification, will fly o
- 2016 Goddard Innovation of the Year
- 6 RTAXs → ½ of 1 Virtex 5

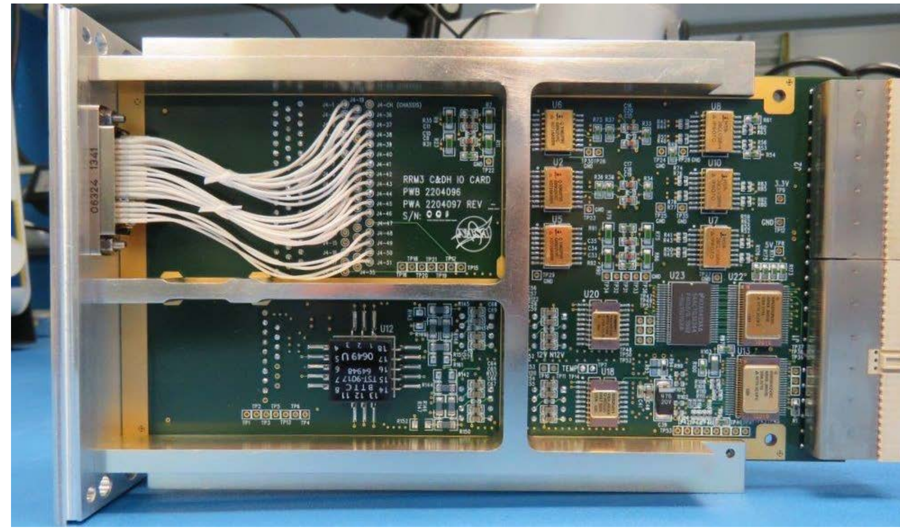
NASA’s Satellite Servicing Projects Division (SSPD) is developing servicing technologies that support science and exploration. SSPD is responsible for the overall management, coordination, and implementation of satellite servicing technologies and capabilities for NASA.

http://sspd.gsfc.nasa.gov

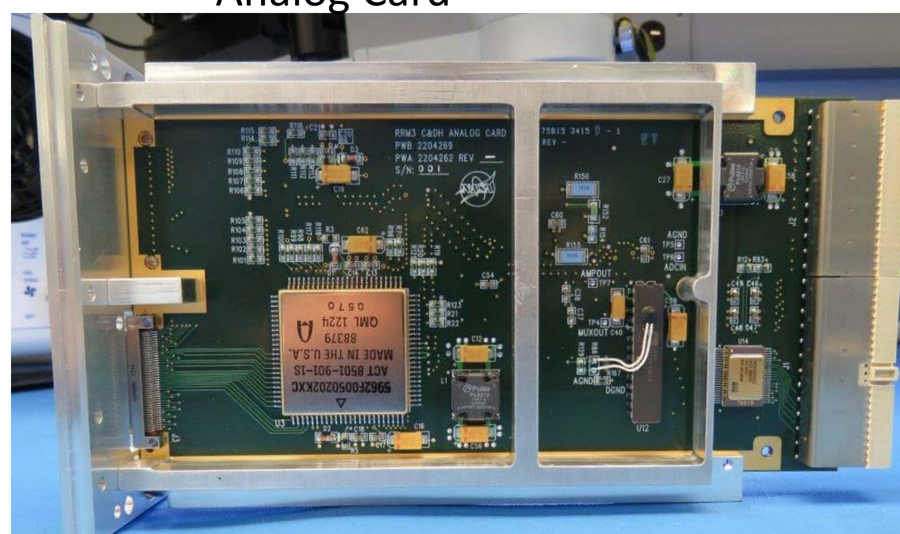
Robotic Refueling Mission 3 SpaceCube



1553/Ethernet/Digital Card



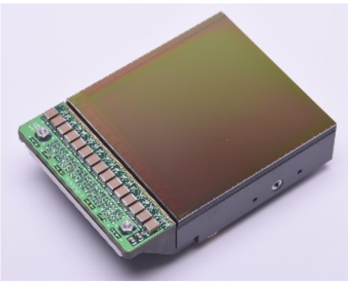
Analog Card



<u>High Level Requirements:</u>

- Interface with ISS and RRM3 instruments:
  - Cameras, thermal imager, motors
- Monitor/Control cryocooler and fuel transfer
- Stream video data
- Motor control of robotic tools
- Host Wireless Access Point

NEODaC Instrument Development



21-ft

> 12 Gbps

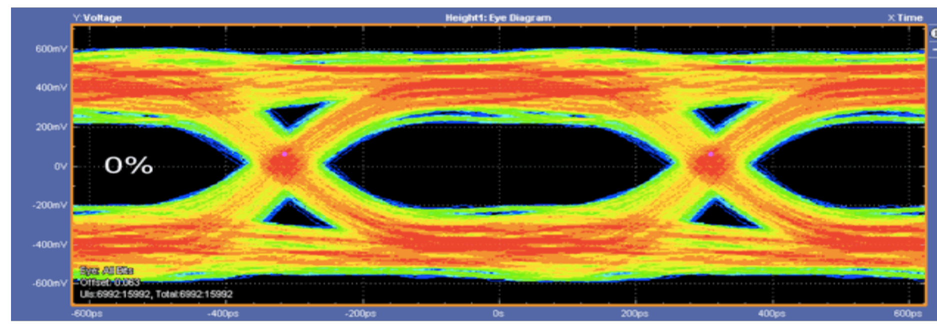
21-ft

8x 1.6Gbps ch.

Host Interface

8x 3K x 3K detectors

Xilinx GTX Driver: 1.6Gbps, 1300mV, vary Pre



- Near Earth Objects Detection and Characterization
  - Funded by NASA SMD/Planetary
- SerDes output drivers over 21-ft.
- SpaceCube FPGAs being used to interface with detectors, host on-board data processing applications and compression
- Successful multi-detector readout with SpaceCube completed during TVAC
- Flight system: 8 Processor Cards

SerDes Link Test Results

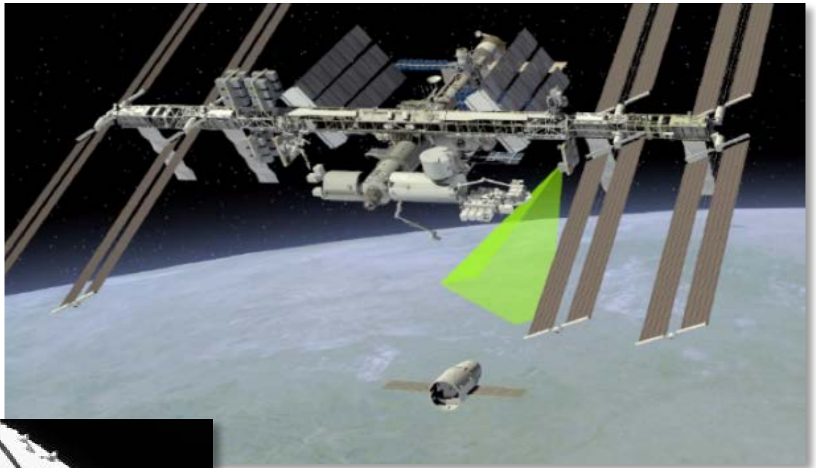
Transmitter Swing (mV)	Transmitter % Pre-emphasis	Test Duration	Bit Error Count	BER (*)
500	0	6hr	32	9.2E-13
500	8	18hr	0	9.6E-15
800	0	4hr	4	1.7E-13
800	25	20hr	0	8.7E-15
1300	17	20hr	0	8.7E-15
1300	0	19hr	52	4.7E-13

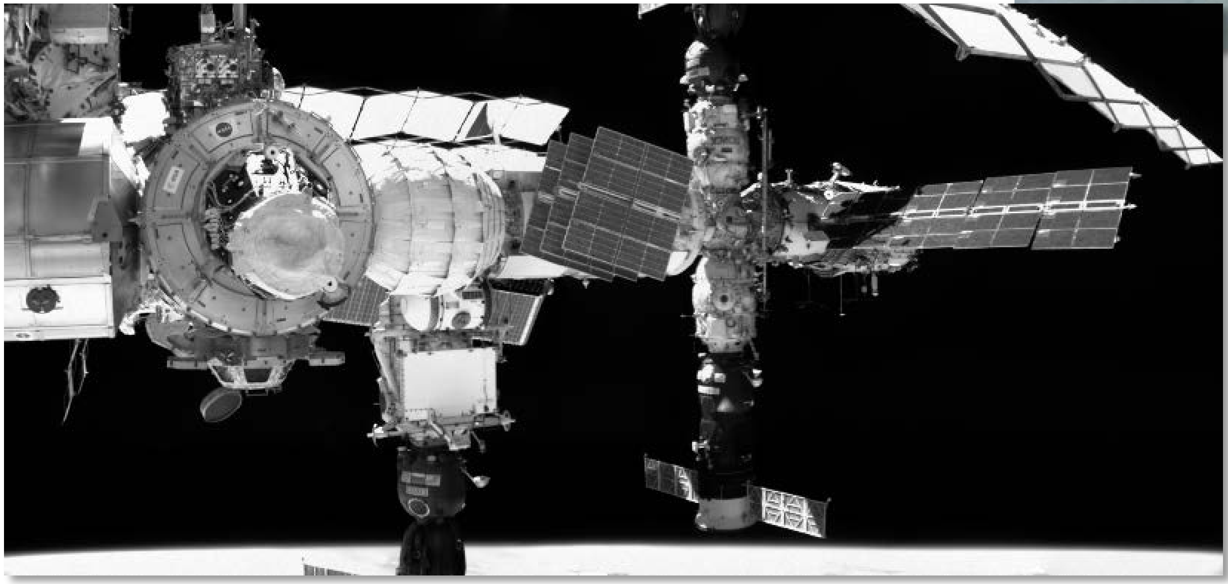
- *Note: BER calculation assumes at least 1 error*
- *58-hours of error-free transmission*

Raven – Relative Navigation

Raven is a technology demonstration experiment on the Space Test Program-Houston 5 (STP-H5) payload, launched to the ISS on the SpaceX CRS-10 mission in February, 2017. During its two year mission on ISS, it will advance the state-of-the-art in NASA's relative navigation capabilities.

- Raven contains three sensors (visible, infrared, lidar), a high-performance & reliable computing platform (SpaceCube) and advanced machine vision algorithms
- Raven will track visiting vehicles to ISS, developing an "off-the-shelf" relative navigation capability for NASA



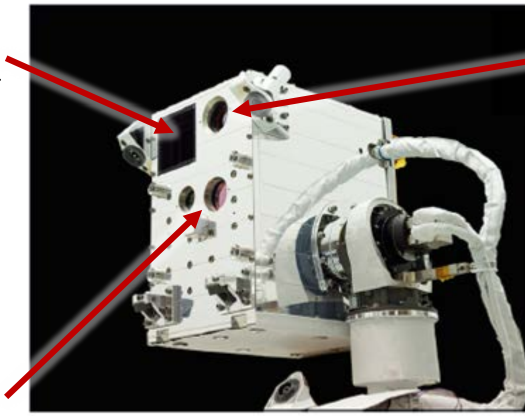


Raven Payload

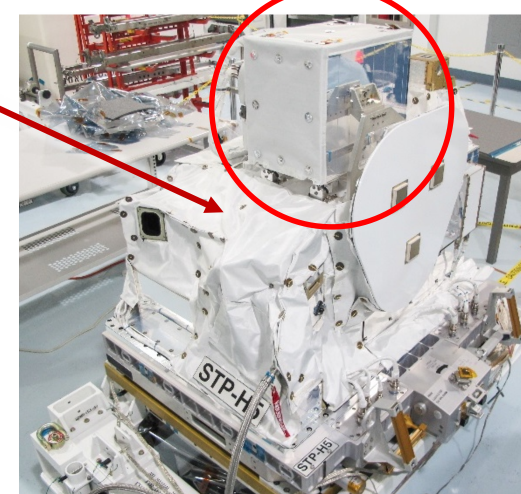
Objective:

To advance the state-of-the-art in rendezvous and proximity operations (RPO) hardware and software by:

- Providing an orbital testbed for servicing-related relative navigation algorithms and software
- Demonstrating relative navigation to several visiting vehicles:
  - Progress
  - Soyuz
  - Cygnus
  - HTV
  - Dragon
- Demonstrating that both cooperative and non-cooperative rendezvous can be accomplished with a single similar sensor suite



Raven
(Deployed Configuration)



Raven installed on STP-H5
(Stowed Configuration)

Raven – Sample Data

Raven is currently generating valuable science that is reducing the risk for future NASA missions that require rendezvous and proximity operations systems

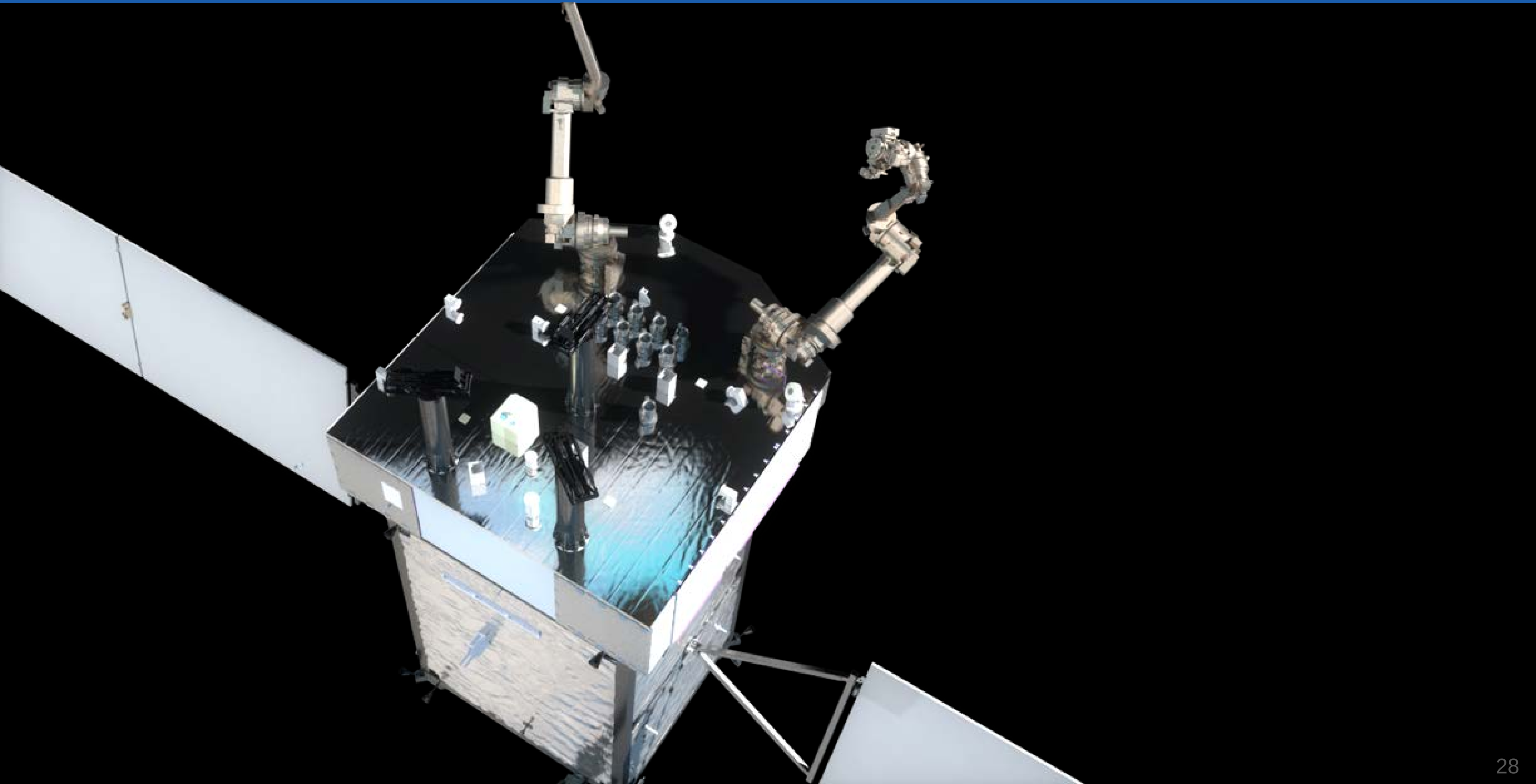
Dragon Tracking (VisCam)

Raven demonstrated successful on-board vehicle tracking during SpaceX CRS-10 departure

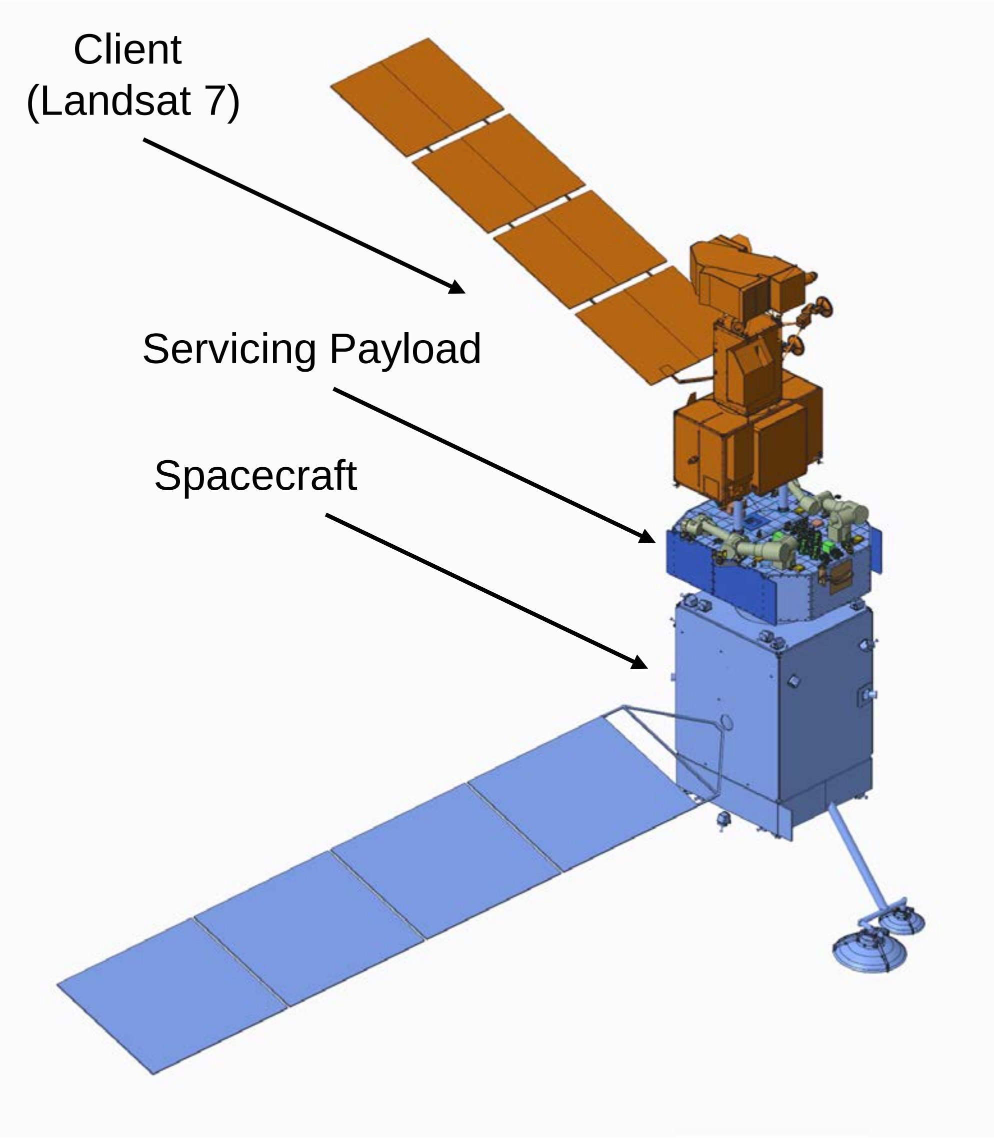
Restore-L Technology Demonstration Project

The Restore-L Project will:

1. Demonstrate national satellite servicing capabilities
2. Advance essential technologies for NASA and national goals
3. Kick-start a new U.S. commercial servicing industry

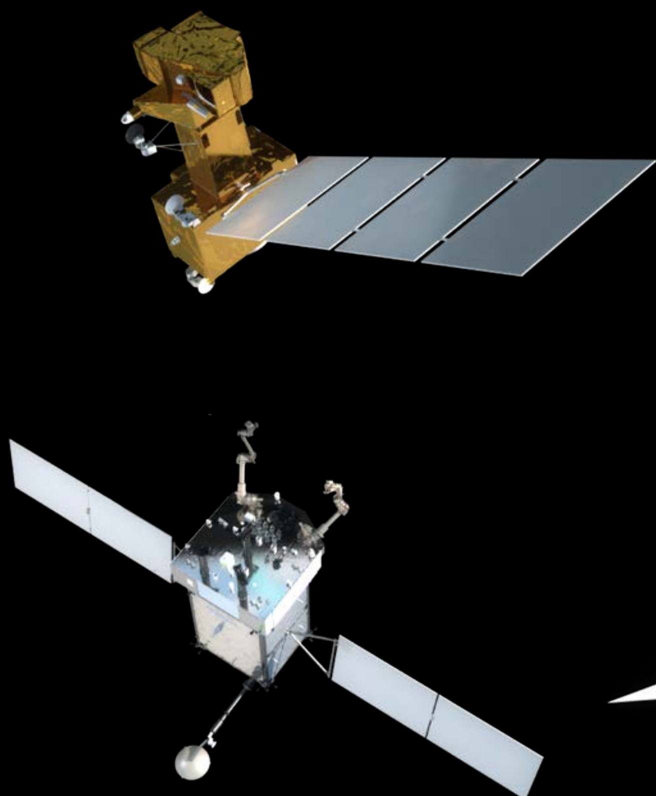


Restore-L Servicing Vehicle Overview

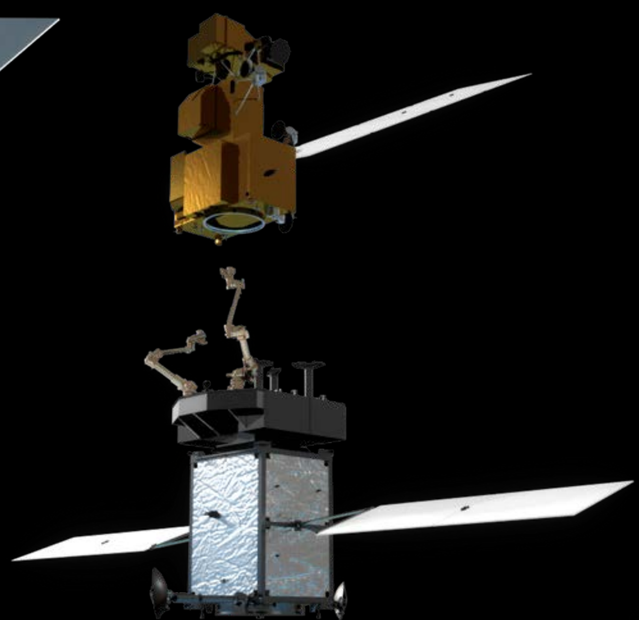


Class/Category	Class C (NPR 8705.4) Category 2 (NPR 7120.5E)
Mission Life	1 year
Launch Vehicle	Domestic: Atlas V, Falcon-9
Launch Site	VAFB
PM Requirements	NPR 7120.5E Tailored
Client	Landsat 7
Other Potential Clients	Understudy clients identified

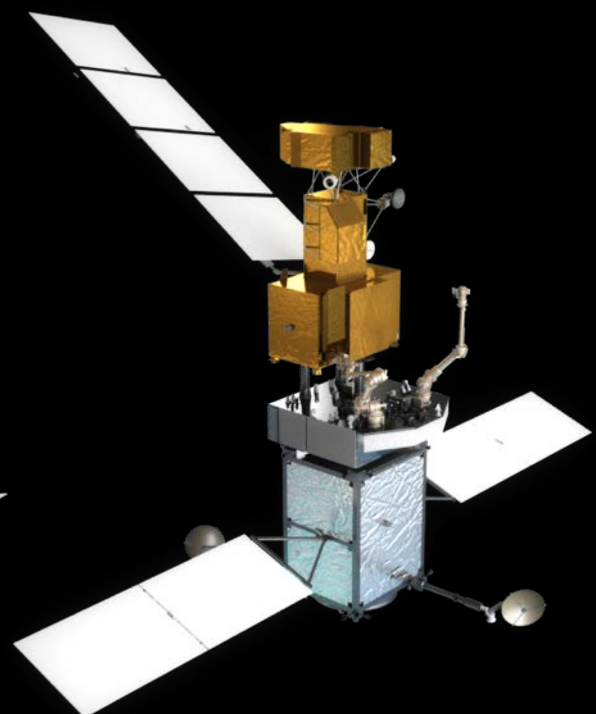
Restore-L Objectives



Autonomous Rendezvous, Inspection



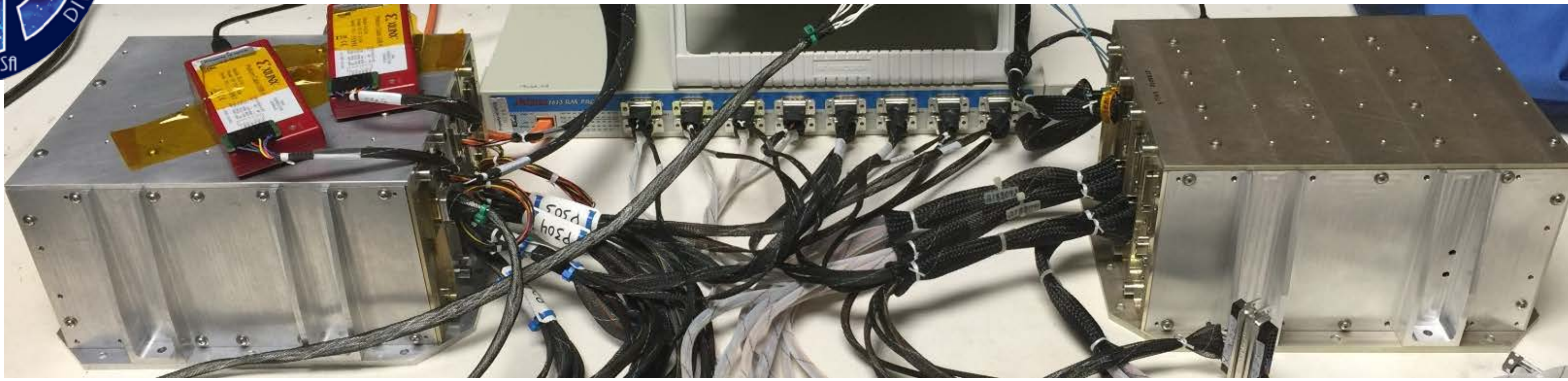
Autonomous Capture



Telerobotic Refuel & Relocate

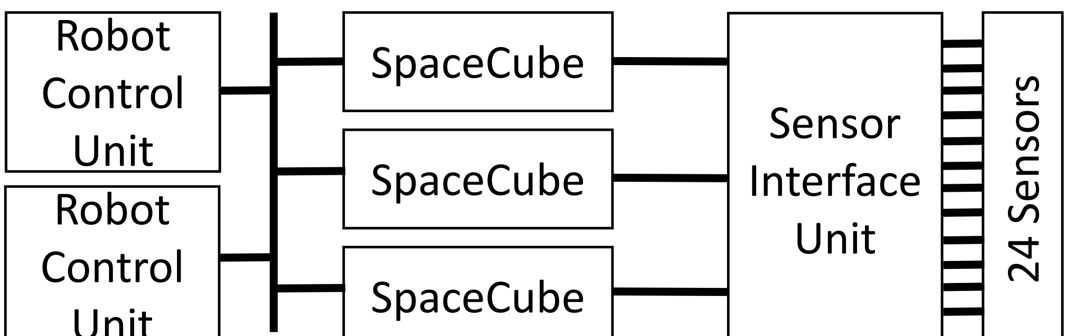
Restore-L Capture and Refuel Video

Restore-L Payload Computer: 3 SpaceCubes

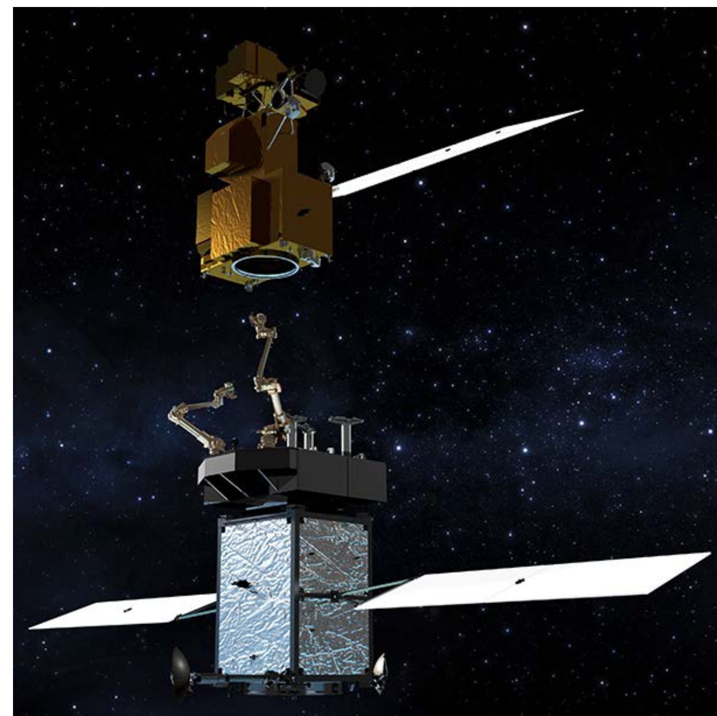


Restore-L Dual SpaceCube Payload Control Computers

<u>High Level Requirements:</u>
- Interface with Spacecraft and Payload Busses
- Interface with vision sensors
- Host Relative Proximity Operations application
- Host Robotic Manipulation Control application



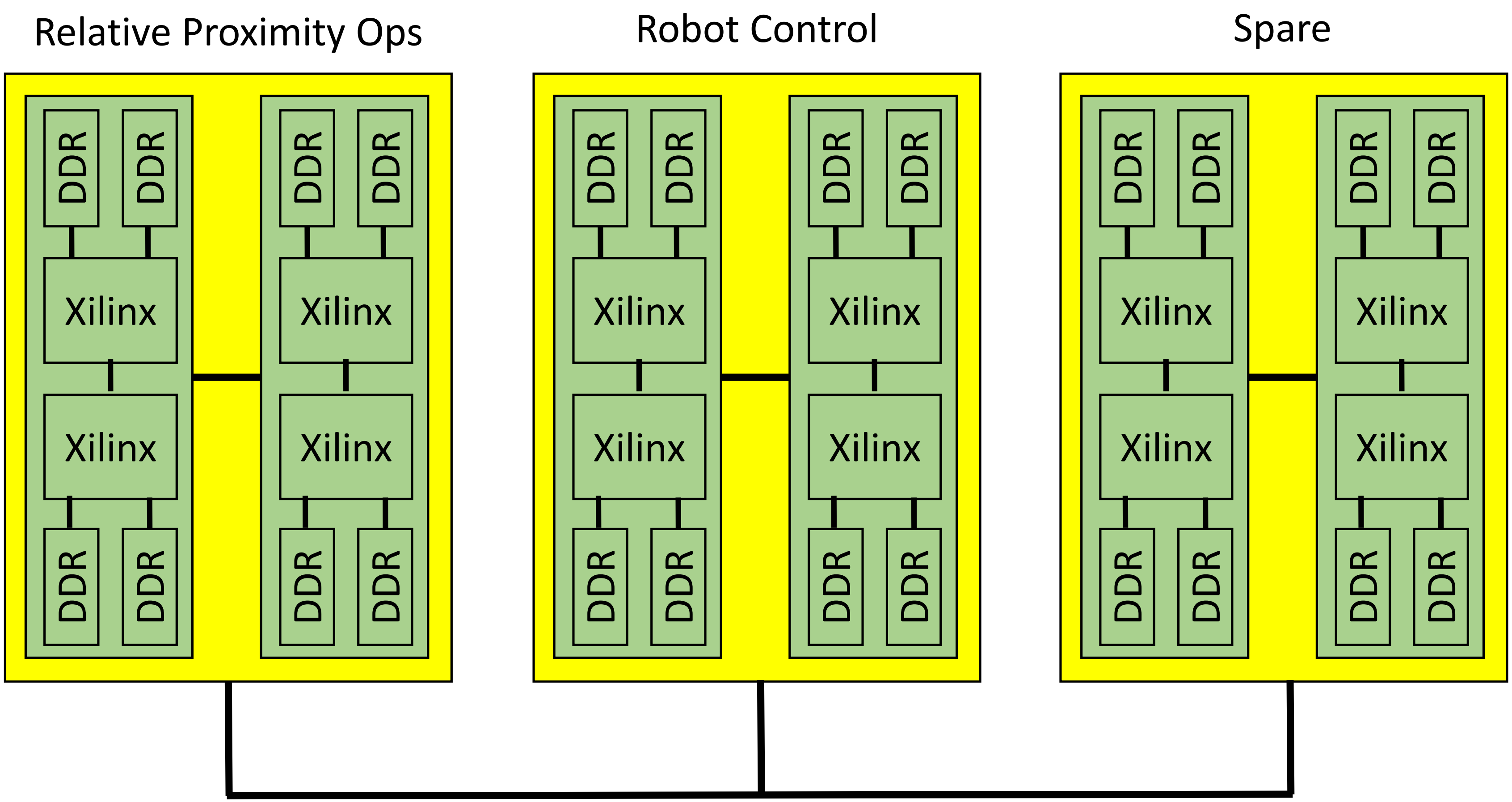
Restore-L will fly 21 Xilinx Virtex-5 FPGAs



Restore-L Capture of Landsat 7

Radiation Effects Mitigation

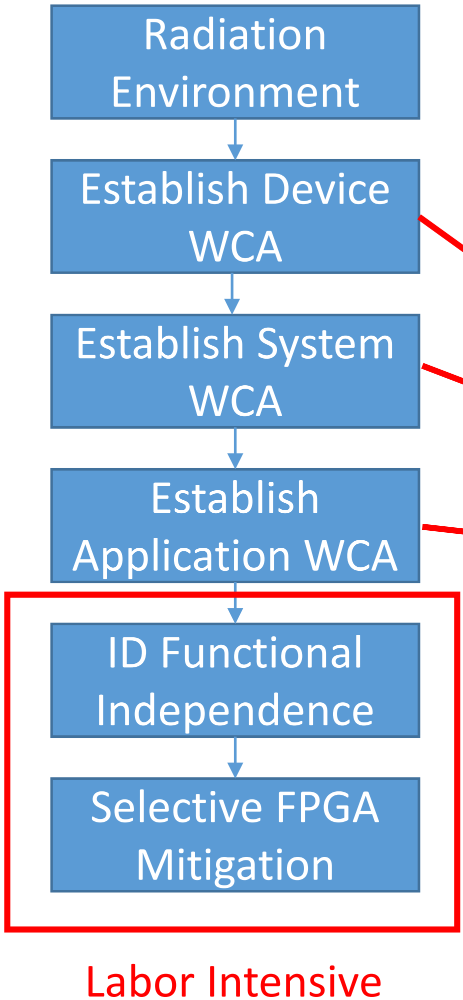
Restore-L SpaceCube Data Processing Architecture



If Spare is "Cold", then worst case error probability: Pe(sys) = [8x Pe(Xilinx) + 16x Pe(DDR)]

Establishing Acceptable SEE Error Rates Using a Risk-based Engineering Analysis Approach

Assessment Process



NASA Risk Assessment

Likelihood	Safety Estimated likelihood of Safety event occurrence	Technical Estimated likelihood of not meeting performance requirements
5 Very High	$(P_{SE} > 10^{-1})$	$(P_T > 50\%)$
4 High	$(10^{-2} < P_{SE} \leq 10^{-1})$	$(25\% < P_T \leq 50\%)$
3 Moderate	$(10^{-3} < P_{SE} \leq 10^{-2})$	$(15\% < P_T \leq 25\%)$
2 Low	$(10^{-5} < P_{SE} \leq 10^{-3})$	$(2\% < P_T \leq 15\%)$
1 Very Low	$(10^{-6} < P_{SE} \leq 10^{-5})$	$(0.1\% < P_T \leq 2\%)$

		100% Device Utilization WCA		Estimated Restore WCA Upset Rates		
Mode	Time (s)	Device WCA	PCC WCA	RPO PCC	RSW PCC	RPO + RSW
one orbit (96 minutes)	5760	0.484%	1.934%	1.074%	0.222%	1.296%
Rendezvous (30 min)	1800	0.151%	0.604%	0.336%	0.069%	0.405%
Capture (77 sec)	77	0.006%	0.026%	0.014%	0.003%	0.017%

Note: assumes BRAM Mitigation

Note: Actual utilization for RPO and RSW PCCs as of 4/18/2016

Note: assumes RPO & RSW PCCs must be error-free for full operation

(Yes, we will be routinely scrubbing the configuration)

Next Year's Talk:
The Restore-L FPGA Design Challenge

Subsystem	Qty	FPGA/Unit	Total FPGAs
SpaceCube	3	6	18
VDSU	2	2	4
PSU	1	44	44
REU	2	12	24
Tool Drive	2	1	2
Camera	13	1	13
RPO VisCam	3	1	3
RPO IRCam	1	1	1
RPO LRF	1	3	3
RPO LIDAR	1	2	2
			118!!!

FPGA Types
- Xilinx Virtex 5
- RTG4
- RTAX
- Aeroflex
- RTProASIC3

Topics
- Process
- Manpower
- Reuse
- Radiation
- Verification

Wrap-Up

- Cross-Cutting Technology
  - Technology leveraging and spin-offs
- Reconfigurable + Modularity
  - Reduced cost and schedule
  - On-orbit adaptation to new mission requirements

9 Mission-Unique SpaceCube v2.0 I/O Cards

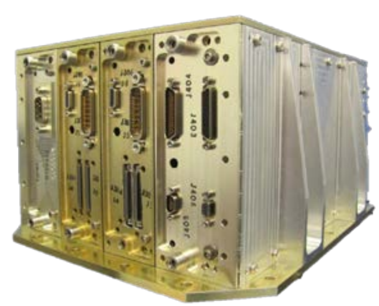
- Flight-Proven Technology
  - 8 flights since 2009
  - 7 upcoming flights
  - Many more in the works

100% Success Rate

- NASA's most forward-thinking organization has infused the technology in ALL current and future projects
- Non-NASA customers
- Licensed to Build: Genesis Engineering Solutions

2 Patents, 7 Pending

- What's next?



SpaceCube
v3.0

Questions?

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https://spacecube.nasa.gov/